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NKS/SRV Seminar on **Barents Rescue 2001 LIVEX** Gamma Search Cell

Edited by

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and

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April 2002

Abstract

Proceedings of the NKS/Barents Rescue 2001 LIVEX seminar, held at Rosersberg Castle, Stockholm, on October 23-24, 2001. At the seminar, results from the Gamma Search Cell of the Barents Rescue 2001 LIVEX were presented and the performance and experiences of airborne and car-borne teams that took part in the exercise were evaluated. In the Gamma Search Cell, the mobile teams found about 50 % of a large number of radioactive sources hidden within the exercise area. The exercise demonstrated that it is necessary to practise and test equipment under out-door conditions. By which method a source is found is important information in the evaluation of the result. Complementary methods are necessary to find hidden sources. For heavily shielded sources methods based on scattered radiation should be developed.

Keywords

Emergency Preparedness; Gamma Spectroscopy; Radiation Monitoring; Radioactive Sources; Nuclear Exercises.

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NKS/SRV Seminar on Barents Rescue 2001 LIVEX Gamma Search Cell

Held at Rescue College, Rosersberg

October 23-24, 2001

Proceedings

Edited by

Thomas Ulvsand, Swedish Defence Research Agency

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Bent Lauritzen, Risø National Laboratory, Denmark

Preface

This report contains the proceedings of the NKS/Barents Rescue 2001 LIVEX seminar, held at Rosersberg Castle, Stockholm, on October 23-24, 2001. The Barents Rescue 2001 LIVEX took place in the surroundings of Boden, Sweden in September 2001. As part of this exercise, the Gamma Search Cell was conducted to exercise airborne and car-borne teams in searching for and identifying lost radioactive sources.

The objectives of the seminar have been to bring together the organizers and participants of the Gamma Search Cell with the aim of enhancing cooperation between Nordic and European mobile teams within nuclear emergency preparedness, to present and discuss team results and experiences of the Gamma Search Cell, and to evaluate the performance of mobile gamma spectrometry in a nuclear emergency. The seminar and these proceedings together aim at the evaluation of the Barents Rescue 2001 LIVEX Gamma Search Cell.

The seminar was organized by the Nordic Nuclear Safety Research (NKS) project BOK-1: Nuclear Emergency Preparedness, in collaboration with the Swedish Rescue Board (SRV) and Danish Emergency Management Agency (DEMA). Special thanks are due to Sven-Erik Lodén, SRV, and Kim Bargholz and Kirsten Juul, DEMA, for valuable help in organizing the seminar, and to the Swedish Rescue Board for sponsoring the seminar.

Bent Lauritzen

Project leader BOK-1

Geographical maps provided in this report:

Contents

Seminar programme

Tuesday, October 23, 2001

09:30-10:00	Registration	
10:00-10:15	Welcome and Practical Arrangements (Bent Lauritzen, NKS/Sven-Erik Lodén, SRV)	
SESSION 1.	**Barents Rescue 2001 LIVEX**	
10:15-10:45	Organization and work in the Gamma Search Cell (Robert R. Finck, SSI)	
10:45-11:15	The radioactive sources and how we arranged them (Thomas Ulvsand, FOI)	
11:15-11:45	Analysis and presentation of results in REAC (Robert R. Finck, SSI)	
11:45-12:00	Experiences of the Gamma Search Cell exercise (Peder Beausang, FOI)	
12:00- 13:00	Lunch	
SESSION 2.	**Team presentations, AGS**	
13:00-14:00	Presentation by team SEC	(Kenneth Lidström, Sweden)
	Presentation by team SEA	(Sören Byström, Sweden)
	Presentation by team NOC	(Thor Engøy, Norway)
	Presentation by team DKA	(Kim Bargholz, Denmark)
14:00-14:10	Break	
14:10-15:10	Presentation by team ATA/ATK/ATL	(Wolfgang Fehringer, Austria)
	Presentation by team FIA	(Markku Kettunen, Finland)
	Presentation by team SEB	(Simon Karlsson, Sweden)
15:10-15:30	Coffee break	
SESSION 3.	**Team presentations, CGS**	
15:30-16:30	Presentation by team FIK	(Jarkko Ylipieti, Finland)
	Presentation by team LVK	(Andrejs Dreimanis, Latvia)
	Presentation by team RUM/RUN	(Sergey Vasiliev, Russia)
	Presentation by team FIL	(Mikael Moring, Finland)
16:30-16:40	Break	
16:40-17:40	Presentation by team LTK	(Arunas Gudelis, Lithuania)
	Presentation by team RUA/RUK/RUK	(EMERCOM, Russia)
	Presentation by team NOL	(Mark Dowdall, Norway)
19:00	Dinner at Rosersberg Castle	

Wednesday, October 24, 2001

SESSION 3. Team presentations, CGS (continued)

08:30-09:30	Presentation by team SEM	(Christer Samuelsson, Sweden)
	Presentation by team NOK	(Mark Smethurst, Norway)
	Presentation by team DKK	(Helle K. Aage, Denmark)
	Presentation by team SEK/SEL	(Olof Karlberg, Sweden)

SESSION 4. Workshop: Monitoring for radioactivity

09:30-12:00 Group discussions. Groups will be formed to discuss topics of mobile monitoring for nuclear emergency preparedness.

12:00-13:00 Lunch

SESSION 4. Workshop: Monitoring for radioactivity (continued)

13:00-14:30 Presentations by group representatives

14:30-15:00 Coffee break

SESSION 5. Future work

15:00-15:30 Discussion: How can we improve co-operation concerning emergency preparedness?

15:30-16:00 ECCOMAGS (Hans Mellander, SSI)

16:00 End of workshop

Session 1

Barents Rescue 2001 LIVEX

Description of the Gamma Search Cell Exercise

Robert R. Finck, SSI

The Swedish Rescue Services Agency was commissioned by the Swedish Government in 1999 to plan and conduct an international exercise on the theme of a nuclear emergency. The exercise, named Barents Rescue 2001, was to take place in the northern part of Sweden during 2001 and conducted as a civil exercise with the support of military resources. Several Swedish authorities were ordered to take part in the exercise. Invitations were sent out to the European countries Austria, Denmark, Estonia, Finland, Germany, Iceland, Latvia, Lithuania, Norway, Poland and Russia. Several other countries were invited to participate with observers. Altogether 24 countries participated in the Barents Rescue 2001 exercise.

The aim of Barents Rescue 2001

The aim of Barents Rescue 2001 was to

- improve the international civilian - military cooperation in rescue services,
- improve the capability to cooperate and lead rescue services for large accidents,
- improve the capability to assess a radiological emergency based on measurements,
- improve the capability to provide information on measures taken in large accidents,
- gain knowledge and create contacts across boarders between authorities and people.

It was early decided that the planning of the exercise should be done in international cooperation between countries invited. Three international planning conferences were held, the Initial Planning Conference (IPC) 10 - 11 May 2000 in Boden, the Main Planning Conference (MPC) 8- 9 November 2000 in Luleå and the Final Planning Conference (FPC) 17 - 19 June 2001 in Kiruna. In addition a number of workshops were held with detailed planning of different parts of the Barents Rescue exercise.

In the planning process it was decided that Barents Rescue should contain different sub-exercises with different themes and time-scales in order to illustrate different aspects of nuclear and radiological emergencies. The early phase of a nuclear emergency was tested in the international alarm exercise ALEX in March 2001. It was a surprise alarm exercise involving a fictitious nuclear power plant in Sweden. Participating countries took part in the exercise from their own emergency response centres in each country.

The final part of the Barents Rescue exercise, the LIVEX (Live Exercise), was aimed at a joint international exercise with monitoring and rescue teams in place in Sweden. After lengthy discussions within the international planning groups it was concluded that it would be difficult to conduct a realistic large scale field exercise in the northern part of Sweden on the theme of a nuclear power accident. This is because distances to actual nuclear power stations are too far to generate heavy life-threatening fallout in this part of Sweden. Instead it was decided to use a different scenario with lost radioactive sources. This kind of accidents has occurred, for example the Cosmos-954 re-entry over Canada in 1978 and the Goiânia accident in Brazil 1988. Such events could lead to the need for international assistance with airborne and car-borne measurements, medical treatment of irradiated people, evacuation and decontamination of highly radioactive areas, etc.

General design of the Gamma Search Cell exercise

During the main planning conference it was decided that a challenging exercise would be a large scale search for orphan gamma radiation sources, simulating a radiological emergency with lost radioactive sources. This part of the LIVEX was named the Gamma Search Cell (GSC). The theme of lost sources was also used in the Command Exercise and the Field Exercise that were part of LIVEX.

According to the LIVEX scenario an unknown number of radioactive sources were suspected to have been illegally buried in the large bogs and forests of northern Sweden in the 1950s and 60s. For some reason, perhaps due to a road construction, at least one of the buried sources had reappeared and caused radiation injury and the death of people. Parts of this source, and possibly other sources, could have been spread over of thousands of square kilometres. The task for the search teams of the Gamma Search Cell was to locate as many sources as possible within the areas defined by the exercise management.

The search for orphan gamma radiation sources over large areas was designed to be a practical experiment were different teams, measuring equipment, assessment methods and tactics could be compared. Rapid positioning and identification of sources found including the reporting of source data to a Radiological Emergency Assessment Centre (REAC) was encouraged to obtain a situation that would be as close to the demands of a real emergency situation as possible.

About 10 helicopter search teams and 15 car-borne search teams had announced their participation in the GSC-exercise. Quite large areas were needed to hide the sources since each team should be able to perform their search without interference from other teams that could reveal source locations. The exercise was set to continue for three days and each team should have the possibility to locate a number of sources each day. This would need at least, as many sources as there were teams. For car-borne teams the road lengths had to be at least a hundred kilometres each day. For airborne teams, search areas requiring at least a couple of hours of flight time each day were needed. The I19 Regiment of the Swedish Armed Forces in the town of Boden offered suitable areas covering these demands. The Regiment arranged for the use of several hundreds of square kilometres of its exercise grounds (firing ranges) northwest and southwest of Boden.

The I19 exercise grounds were large, but not large enough to allow all teams to obtain completely separate search areas. The number of available radioactive sources that could be used in the exercise was also limited. Therefore, a compromise between realism and efficiency was made in such a way that teams had to share search areas. For car-borne teams, five search areas were defined (C1 - C4, C7). These should be covered during the three days of exercise. 1 - 8 sources were placed in each area. This meant that 3 - 4 car-borne teams had to use the same area at the same time. To allow all car-borne teams to have the same prerequisites within each area, information on identified source locations had to be kept secret between teams until the end of the exercise.

In a real situation the findings from airborne search would be followed up on the ground with hand held equipment. The exercise management decided that this practice should be allowed and encouraged in the exercise. Therefore, all car-borne teams were granted access to results from at least one airborne team. The information exchange between airborne and car-borne teams was assigned country by country. Countries without airborne teams got access to Swedish airborne results. The time and area slots of airborne and car-borne teams were distributed so that car-borne teams generally were assigned to areas that had been covered by airborne search the day before. Unfortunately, due to morning fog during all three exercise-days, this cooperation between airborne and car-borne teams could not be fully accomplished.

The follow up of sources on the ground required search teams to get close to hidden sources. Since sources should be located by radiation measurements and not by eye, the sources could not be visibly marked. Special safety arrangements were put into practice to allow teams to operate safely in the search areas with hidden sources. Physical arrangements of different kinds were built around all sources to prevent people and wildlife to get in touch with the sources. Access to the exercise grounds was legally restricted and physically stopped using roadblocks. Military radiation protection personnel guarded the areas around the clock. Special arrangements were made to ensure that only the approved search teams taking part in the GSC-exercise had access to the exercise grounds where the sources were placed.

After the end of the three exercise days the source locations, radionuclides and activities of all hidden sources were published and the measurement data from all teams shared among the participants of the GSC.

Responsible authorities and support

The authorities responsible for planning and conducting the GSC-exercise were the Swedish Rescue Services Agency (SRV), the Swedish Radiation Protection Authority (SSI), the Swedish Defense Research Agency (FOI) and the Swedish Armed Forces (FM).

In November 2000 the Nordic Nuclear Safety Research (NKS) decided to support teams from the Nordic countries for their participation in the Gamma Search Cell. This made it possible for some teams to participate. The support of NKS also made it possible to compile this report.

The radioactive sources and how they were arranged

Thomas Ulvsand, FOI

The purpose of the exercise was to find and identify various gamma-emitting radioactive sources. According to the LIVEX-scenario you would expect the sources to be unknown, hidden, buried or in other ways hard to find and to identify. This was the situation we wanted to create for the exercise. We also had to consider radiation protection aspects. The arrangements must be able to perform in a safe way giving minimal doses to the managing personal, according to the ALARA-principle. The arrangements also had to ensure that doses to measuring teams or to the public by mistakes were avoided.

The sources we used were borrowed, rented or bought from national suppliers of radioactive sources, from hospitals and radiography companies, from the Swedish Armed Forces and from laboratories. We used 24 Co-60, 11 Cs-137, 2 Mo-99, 2 Ir-192, 1 I-131, 3 natural Ra and 1 Am-241 sources, totally 44, ranging in activity between 0.0004 - 41 GBq.

In the exercise area the sources were placed in shelters, sheds, vehicle carts or in free air with special arrangements for the protection aspects. We used 15 tons of concrete-filled boxes to build shields for protection and to create confusing radiation fields. In some cases we tried to combine two sources of which just one was supposed to be seen from the air. If and when a car search team then entered the area to verify this finding they were supposed to find another source, positioned some distance away. The sources 4:2 and 4:3 and likewise the sources 4:6 and 4:7 are arranged according to that idea.

In the following pages photographs and presentations of each and every one of the sources, nuclide, activity, shielding and other relevant information are given. The Co-60 sources are all of the same type, namely equipment for exercises in training in the Swedish Armed Forces. They are all activated and loaded at the same time, which explains why they all have the same activity.

The position of radiation sources was determined by hand held GPS equipment. The uncertainty in the coordinates given is in the order of 10-20 m. For sources placed in buildings the uncertainty is somewhat larger since the GPS-reading usually was done close to the nearest wall outside the building. This adds an additional uncertainty of 5 - 10 m, i.e. overall uncertainty in the coordinates given of 30 m for sources placed in buildings.

The photographs are taken by Robert R. Finck and Thomas Ulvsand during the planning, preparation and exercise periods. The two aerial views of source 5:2, 5:3 and 5:4 are taken by Staffan Hennigor from Forsmark NPP in Sweden, during the last exercise day.

The blocks that were used as shields are wooden boxes filled with concrete (Figure 1). Their outer dimensions are 720 × 185 × 200 mm and the wood is 22 mm thick.

Figure 1. Concrete block.

Source code: 1:1
Nuclide: Co-60
Activity: 4.9 GBq

Coordinate E: 1756005
Coordinate N: 7298134

In a wooden cage in a gravel pit, shielded upwards with 4 layers of concrete blocks.

Before placing source, shielding and mask

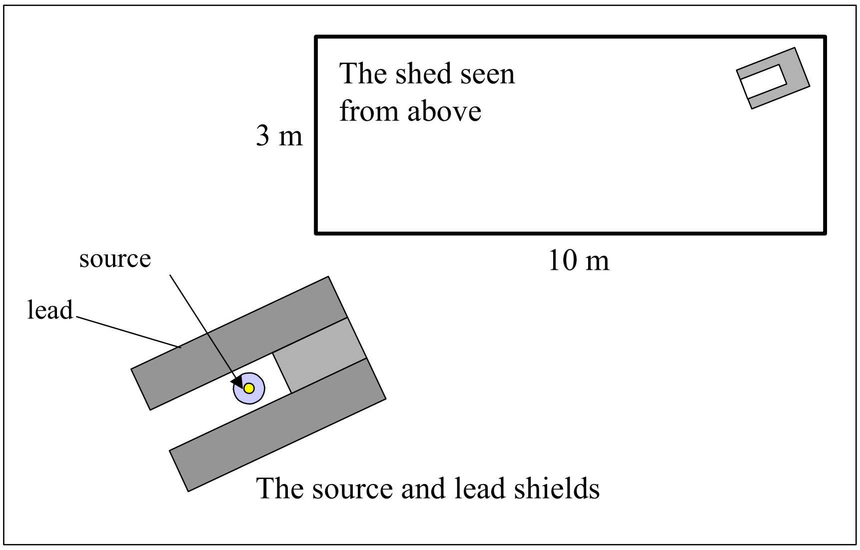
Source with mask and shielding

Source code: 1:2
Nuclide: I-131
Activity: 10.3 – 8.5 GBq

Coordinate E: 1756005
Coordinate N: 7299224

In a shed collimated with lead bricks producing a beam upwards and to the west

The source is placed in a shed in a plexiglass tube between lead bricks



Sketch of the source arrangement

Source code: 1:3
Nuclide: Co-60
Activity: 4.9 GBq

Coordinate E: 1755956
Coordinate N: 7299830

In wooden cage at the end of the road, shielded sideways with concrete blocks.

Before placing source, shielding and mask

Source code: 1:4
Nuclide: Co-60
Activity: 4.9 GBq

Coordinate E: 1756747
Coordinate N: 7300334

In wooden cage on the south side of the closed road, shielded sideways with concrete blocks.

Before placing source, shielding and mask

View from the west

Source code: 2:1
Nuclide: Co-60
Activity: 4.9 GBq

Coordinate E: 1764029
Coordinate N: 7307246

Inside the round concrete bunker. Radiation beam parallel to the ground and directed towards the road.

Before placing the source in the bunker

After placing the source and covering the entrance

Source code: 2:2 **Coordinate E: 1764048**

Nuclide: Co-60 **Coordinate N: 7307266**

Activity: 4.9 GBq

Inside the concrete bunker. Radiation beam directed approximately 30 degrees upwards.

Before placing the source in the bunker Photo from the source position

After placing the source and covering the entrance

Source code: 2:3
Nuclide: Mo-99
Activity: 0.9 – 0.5 GBq

Coordinate E: 1764844
Coordinate N: 7307031

In tracked vehicle cart, collimated upwards with opening angle approximately 45 degrees.

Open generator with the source left inside

Masked vehicle cart with the source inside

Source code: 2:4
Nuclide: Mo-99
Activity: 5.5 – 3.0 GBq

Coordinate E: 1765350
Coordinate N: 7305451

In the house, on the attic.

The house in which the source was placed

Open shield with the source placed behind it

Source code: 2:5-1
Nuclide: Cs-137
Activity: $3\times$ 0.5 GBq

Coordinate E: 1763466
Coordinate N: 7306095

Level guards inside tracked vehicle cart, directed upwards.

Source code: 2:5-2
Nuclide: Co-60
Activity: $3 \times$ 0.02

Coordinate E: 1763466
Coordinate N: 7306095

Level guards inside tracked vehicle cart, directed to SW.

Inside the cart with the Cs-sources to the right and the Co-sources to the left

Finishing the mask on the cart

Source code: 2:6
Nuclide: Am-241
Activity: 0.0004 GBq

Coordinate E: 1760526
Coordinate N: 7302595

In cart, taped on the inside of the plastic hood, about 1.5 m above the ground.

The position of the source is marked with a ring

Source code: 3:1
Nuclide: Co-60
Activity: 4 × 4.9 GBq

Coordinate E: 1766304
Coordinate N: 7316848

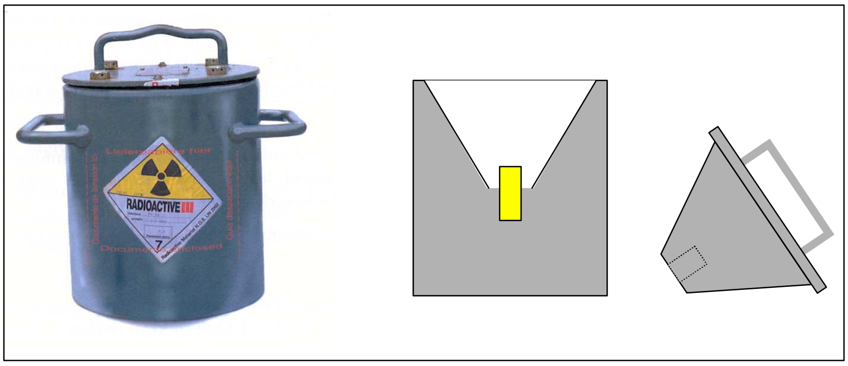
In storehouse 36, shielded sideways with a lot of concrete.

The sources were placed approximately in the middle of the building. They were shielded with 62 cm of concrete towards the long sides of the building and with 32 cm towards the short sides. Four slits in the front direction due to openings for the manoeuvring rods. Some additional shielding with lead cans, corresponding to a thickness of 3 - 4 cm, backwards and sideways.

Source code: 4:1 **Coordinate E: 1760923**

Nuclide: Cs-137 **Coordinate N: 7321390**
Activity: 0.4 GBq

In a red shed, shielded sideways.

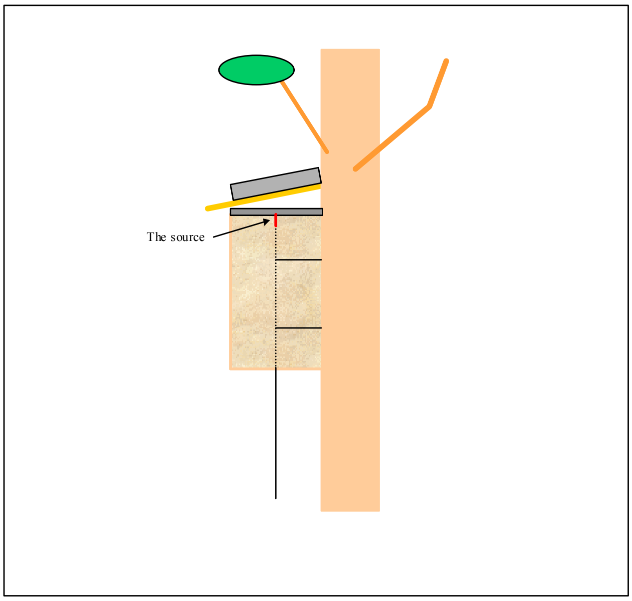


No photo of the shed exists. The source was in a lead container with the lid lifted away

Source code: 4:2 **Coordinate E: 1760488**
Nuclide: Cs-137 **Coordinate N: 7323895**
Activity: 2.5 GBq

In a bird nesting box. Shielded upwards with 6 cm of lead.

The false bird nesting box with a lead brick on the roof. The nesting box is 3 m above the ground



Sketch of the arrangements of the source and the shields

Source code: 4:3
Nuclide: Ir-192
Activity: 12 GBq

Coordinate E: 1760310
Coordinate N: 7323933

Radiographic source in a tree, about 3 m above the ground.

The position of the source is marked with a ring

Source code: 4:4
Nuclide: Co-60
Activity: 4.9 GBq

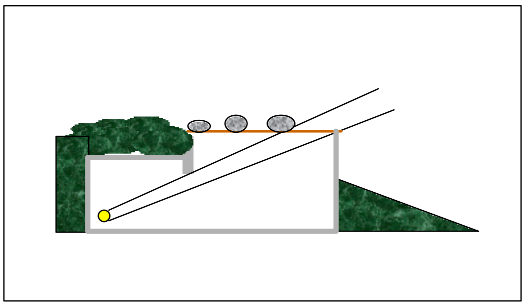
Coordinate E: 1761137
Coordinate N: 7323702

Source code: 4:5
Nuclide: Co-60
Activity: 4.9 GBq

Coordinate E: 1761117
Coordinate N: 7323744

In concrete fire trenches, covered with steel plate and stones. The two trenches are separated by 50 m.

One of the fire trenches

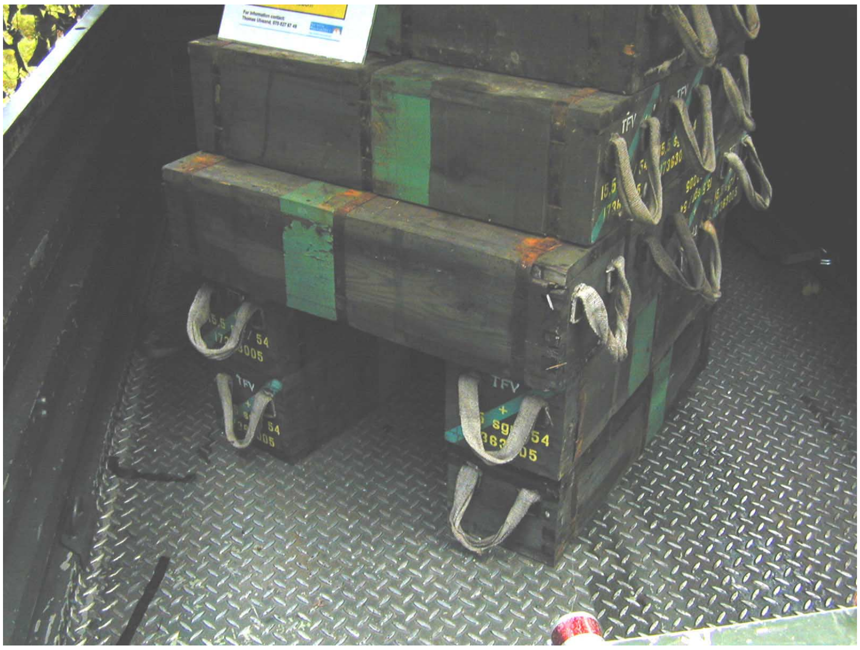


Sketch of how the sources were arranged

Source code: 4:6
Nuclide: Cs-137
Activity: 1.3 GBq

Coordinate E: 1761442
Coordinate N: 7323932

In tracked vehicle cart, shielded upwards with concrete blocks.



The source was shielded upwards with three layers of concrete blocks and collimated in WNW direction towards the terrain track

The source and concrete blocks inside the cart before closing and masking

Source code: 4:7
Nuclide: Cs-137
Activity: 1.9

Coordinate E: 1761559
Coordinate N: 7323941

In tracked vehicle cart, shielded sideways.

The source was collimated with a big angle upwards by just taking the lid away and shielded sideways with two layers of concrete blocks. The photo is taken just before the lid was taken away

The tracked vehicle cart in position in the forest

Source code: 5:1
Nuclide: Co-60
Activity: 40 GBq

Coordinate E: 1756869
Coordinate N: 7322034

Radiographic source in a drainage drum under the road.

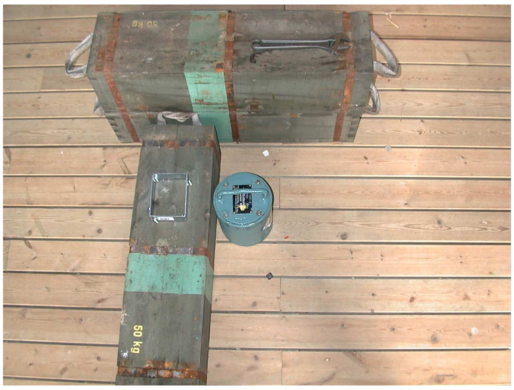
The source position under the road is indicated with a ring

The road drum, the source guide and the transport container.

Source code: 5:2
Nuclide: Cs-137
Activity: 2.6 GBq

Coordinate E: 1755733
Coordinate N: 7321627

In a red shed, no shielding upwards.



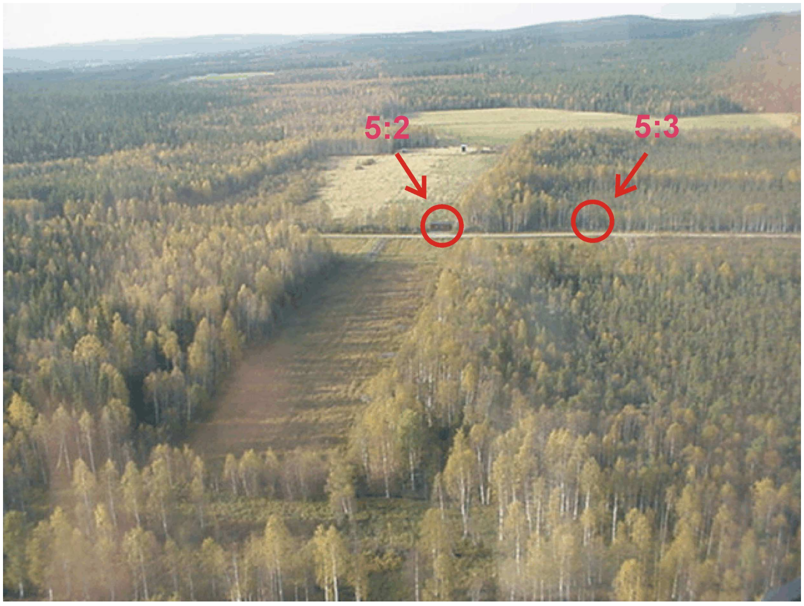
The source was placed into the metal frame, close to the lead container

Source code: 5:3
Nuclide: Co-60
Activity: 2 × 4.9 GBq

Coordinate E: 1755750
Coordinate N: 7321686

In a wooden cage, no shielding.

One of the two sources is opened

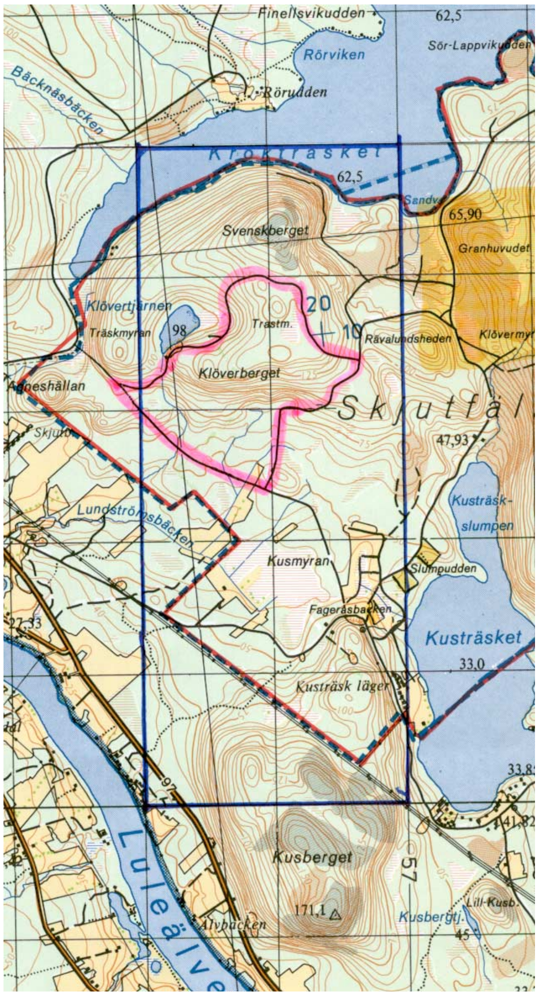


Aerial view of sources 5:2 and 5:3

Source code: 5:4 **Moving between Coordinate E: 175490 - 175670**
Nuclide: Cs-137 **Coordinate N: 732240 - 732400**
Activity: 1.9 GBq

In car cart moving along a road loop, shielded to all sides.

The car and cart seen from helicopter



The road loop

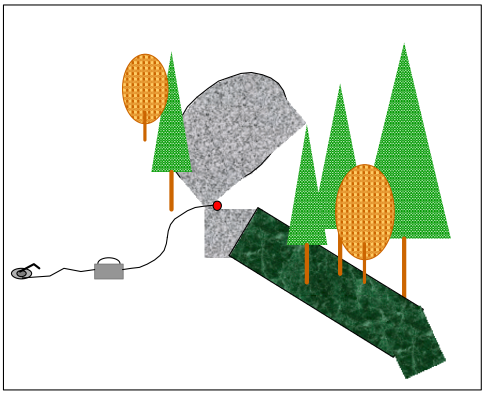
Inside the cart. The ordinary lid was taken away and the source was covered with a thin plastic disc

Source code: 5:5
Nuclide: Ir-192
Activity: 41 GBq

Coordinate E: 1756402
Coordinate N: 7324293

Radiographic source below a boulder.

The boulder under which the source was placed



Sketch of the source arrangement

The source placed under the boulder

Source code: 6:1
Nuclide: Cs-137
Activity: 2.6 GBq

Coordinate E: 1761020
Coordinate N: 7302427

Reference source in a tracked vehicle cart.

Source code: 6:2
Nuclide: Co-60
Activity: 4.9 GBq

Coordinate E: 1761670
Coordinate N: 7302884

Reference source in a wooden cage.

Source code: 7:1
Nuclide: Co-60
Activity: 4.9 GBq

Coordinate E: 1725376
Coordinate N: 7340248

In storehouse 27, source collimated in SE direction.

The source is opened

Source code: 7:2
Nuclide: Co-60
Activity: 4.9 GBq

Coordinate E: 1721169
Coordinate N: 7340769

In storehouse 22, source collimated in ENE direction.

Source code: 7:3
Nuclide: Co-60
Activity: 4.9 GBq

Coordinate E: 1718957
Coordinate N: 7338223

In storehouse 51, collimated towards storehouse 52.

Source code: 7:4
Nuclide: Co-60
Activity: 4.9 GBq

Coordinate E: 1718983
Coordinate N: 7338209

In storehouse 52, collimated towards storehouse 51.

Source code: 7:5
Nuclide: Co-60
Activity: 4.9 GBq

Coordinate E: 1711648
Coordinate N: 7331315

In storehouse 50, source shielded in direction NW over N to SE

No photo of the source exists

Source code: 7:6
Nuclide: Ra-226
Activity: Natural

Coordinate E: 1721282
Coordinate N: 7340593

Source code: 7:7
Nuclide: Ra-226
Activity: Natural

Coordinate E: 1718765
Coordinate N: 7337175

Source code: 7:8
Nuclide: Ra-226
Activity: Natural

Coordinate E: 1712920
Coordinate N: 7318874

Pieces of rock containing Uranium ore, placed in wooden boxes.

Source code: R1:1
Nuclide: Cs-137
Activity: 1.9 GBq

Coordinate E: 1769622
Coordinate N: 7313225

Reference source at the air field in tracked vehicle cart.

Source code: R1:2
Nuclide: Co-60
Activity: 4.9 GBq

Coordinate E: 1769447
Coordinate N: 7313487

Reference source at the air field in tracked vehicle cart.

Source code: X:1
Nuclide: Cs-137
Activity: 1.9 GBq

Coordinate E: 1762946
Coordinate N: 7303659

Pre-exercise source in lead container in cart. Source arrangement was the same as in 5:4

Source code: X:2-1; X:2-2
Nuclides: Cs-137; Co-60
Activity: 0.5 GBq; 0.02 GBq

Coordinate E: 1764308
Coordinate N: 7308519

Pre-exercise sources. Level guards in Volvo, directed towards the road.

Source code: X:3
Nuclide:Cs-137
Activity: 2 × 0.5 GBq

Coordinate E: 1764698
Coordinate N: 7306720

Pre-exercise source. Level guards in Volvo, not opened.

Source code: X:4
Nuclide: Co-60
Activity: 2 $\times$ 0.02 GBq

Coordinate E: 1764300
Coordinate N: 7306424

Pre-exercise source. Level guard in Skoda, directed towards the East.

Source code: X:5 **Coordinate E: 1763856**
Coordinate N: 7305822
Nuclides: Cs-137; Cs-137; Cs-137; Co-60; Co-60; Ba-133
Activity: 1.3; 1.9; 0.4; 0.1; 0.1; 0.004 GBq

Pre-exercise source in transport lorry. All sources in closed lead containers.

Photo taken at other location

The Gamma Search Cell and Radiological Emergency Assessment Centre, REAC

(From the Exercise Specification)

Robert R. Finck, SSI

The Gamma Search Cell in Barents Rescue LIVEX 2001 conducted an exercise aimed at search and identification of orphan radioactive sources over large areas. Gamma emitting sources of different radionuclides were used. The number of radiation sources, their locations and activities were not revealed to the participants in advance. The task for each participating team was to determine the position, radionuclide, activity and dose rate of as many sources as possible within the assigned search area and time allotted and to report the findings as soon as possible to the Radiological Emergency Assessment Centre, REAC.

Participation and equipment

Participation in the Gamma Search Cell was open to teams using fixed wing aircraft, helicopters and cars. Measuring equipment was gamma spectrometers based on sodium iodide crystals or semiconductor detectors based on high purity germanium. Teams could also participate with non-spectrometric instruments such as geological survey instruments and dose rate meters.

Time schedule

Most participating teams arrived in Boden on Wednesday, September 12. An opening and information meeting was held on September 13. Information on activities concerning reference measurements and pre-exercises was given in the mornings of September 14 and 15. Detailed orders for each exercise day were given in the evening of September 16, 17 and 18. On September 16 a pre-exercise was conducted during three hours. In the afternoon of September 13 the official LIVEX opening ceremony was held. The main exercise took place during September 17 - 19. Source locations and results from teams were presented in the morning of September 20.

Airborne search for orphan gamma radiation sources

Helicopters were allotted to five search areas of 2 x 5 km^2 (A1-A5). Only one helicopter was allowed into a search area during a time slot (A single exception was made for three Swedish military helicopters flying in formation in area A5 during the last hour of the exercise). The time allotted to each search area was about 50 – 55 minutes. During the three exercise days there were 7 - 8 time slots per day for each search area. However, due to fog in the mornings, only afternoons could be used for airborne search.

A specific training area 3 x 3 km^2 (A6) was assigned. In this area two radiation sources (Co-60 and Cs-137) were well marked and visible from the air. The training area was open from September 13 until September 19. In addition, two radiation sources (Co-60 and Cs-137) were available for reference measurements at the aviation field. Airborne teams were provided with maps of the search areas.

Helicopters were allowed to fly at their own choice within the borders of the search areas, but were not allowed to land there. The minimum flight height was 60 m due to the safety distance to sources. There was unassigned space between individual search areas allowing helicopters to make close turns just outside the area. One fixed wing aircraft participated also. It was given time slots when helicopters were not in the air. The Air Wing performed command and control of all airborne activities.

Helicopter teams reported source findings to REAC within one hour after landing. A specific Source Identification Report (SIR) was used. In addition, teams could report more detailed measurement data at their own choice. Details concerning reporting procedures and data formats were provided separately.

The search areas are shown in Appendix 1.

Car-borne search for orphan gamma radiation sources

Car-borne search teams were given different areas and roads to search. Four (A1-A4) of the five search areas assigned to airborne search were also open for car teams and teams on foot with portable equipment (corresponding to car-borne search areas C1-C4). About 300 km of roads were available for car-borne search and divided into five sub-areas (C1-C4, C7). Typically 3 - 6 car teams shared one sub-area. Teams were allowed to leave their car and perform search on foot in the terrain with portable equipment.

Car-bone teams had access to radiation sources for training and reference measurement in the specific training areas at A6 and at the helicopter airfield. Access to the training area at the airfield was allowed from September 13 and at the A6 area from September 14.

All teams were provided with road maps showing search roads and areas. The area A5 was only assigned to airborne search and not open for car-borne search or search on foot.

As soon as a team found a radiation source, its position, radionuclide and estimated activity should be reported to REAC.

The search areas are shown in Appendix 1.

Cooperation between airborne and car-borne teams

Cooperation between a helicopter team and a car-borne team was allowed for each participating country. Measurement results could be exchanged through the web site maintained by REAC. Countries without a helicopter could obtain information from Swedish airborne teams. Time slots were generally allocated so that car-borne teams should be able to use data from airborne teams that had been in the area the previous day. The car-borne team could then follow up and more closely identify and quantify sources on the ground that have been identified from the air. However, due to the morning fog this cooperation could not be fully accomplished.

Presentation of results and scientific evaluation

Source findings were reported on the Source Identification Report. Reporting was made by telephone, fax or email to REAC. Track measurement data was reported on data media or by email in the specific NKS-format. The NKS-format was first used during the Resume 99 exercise in Gävle.

A password protected web site was used to display results from all participating teams in the Gamma Search Cell. Each team had access to its own results on the web, but different teams could not see each other’s results until the end of the exercise. At that time all results were made available to all participants together with details on source data. General information about teams, the progress of the exercise and other information of general interest were provided on a web site open to the public.

The Nordic Nuclear Safety Research, NKS, supported participating teams from the Nordic countries. NKS collected measurement information from all teams to facilitate a subsequent scientific evaluation of measured results. Generally all participating teams will be allowed to use all data that have been reported to REAC and documented. When using data from other teams in scientific reports, these teams should be duly referenced and acknowledged.

A follow-up meeting for all participating teams was held at Rosersberg on October 23 - 24, 2001. At this meeting, participants presented their measurements and experiences from the exercise. The written contributions are included in the proceedings of this joint measurement report.

Radiation safety

The exercise was conducted with high radiation safety demands. The Swedish Radiation Protection Authority stated conditions for the use of radiation sources in the exercise and issued the permission according to the Swedish legislation.

The firing ranges around Boden were used for placing the radiation sources in the Gamma Search Exercise. Airborne and car-borne teams had access to these areas, but the areas were prohibited for the public to enter. All teams were provided with special identification tags and car signs to allow admittance to the restricted areas. Teams entering and leaving the restricted areas had to report to the Ground Control in REAC.

Radiation sources were placed behind barriers so that no person could inadvertently come close to them. In addition, strong radiation sources were only placed in areas legally off-limits to the public. The sources were locked in such a way that they could not be removed from their places without using physical force. Exercise areas were guarded around the clock by a specially assigned organisation.

All persons participating in the Gamma Search Cell had to carry dosimeters. These were supplied by the exercise management at the start of the exercise and collected after the exercise. Teams could also use their own dosimeters, but it was obligatory to carry the special dosimeters supplied by the management. In addition, all participating search teams were encouraged use dose rate instruments.

There was one specific person responsible for radiation safety.

Security

The Host Nation Support (HNS) was responsible for guard duties. Secure areas for parking of cars with equipment was provided. Helicopters were guarded round the clock.

Web sites

The web site http://barentsrescue.srv.se was the main site for information concerning the Barents Rescue LIVEX 2001. Measurement data from the Gamma Search Cell was made available to search teams on the password protected web site http://barentsrescue.ssi.se.

Search results and conclusions

Thomas Ulvsand, FOI

Robert R. Finck, SSI

The search results for all teams are graphically presented in Figure 2 on the next page. The presentation is based on Source Identification Reports (SIR) used during the exercise, the team's written reports in these proceedings, and in some cases a judgement from the authors if a source is found or not. By which method a source was found is not possible to see from the graphic.

It is a difficult task to find and identify hidden radioactive sources; the results of the Barents Rescue Gamma Search Cell exercise clearly indicate that. It is of course possible in a real accident that the source activities are stronger and that you know what type of nuclide you are looking for. Nevertheless the exercise gave the participating teams a good opportunity to practise and test their equipment and search strategy. Most teams found it very valuable to have their equipment tested under out-door conditions, mounted in vehicles and bumping around on gravel roads or in helicopters and with a limited time at their disposal. Many problems had to be dealt with like broadening of photo peaks and to optimise between detector systems. Background discrimination, how the system alerts when passing a source, on-line or post processing of data, and accurate positioning are other examples. No team found all sources, and a few sources were not found at all. The results for the different teams show a big variety, but every team found at least some sources.

Due to the fact that the mornings during the three exercise days were to foggy to allow flying in the area, there were limitations in flying time for the air teams, compared to what was scheduled. This affected the results as the time accessible for air gamma search was very short for each team, to get as many teams as possible an opportunity to participate in the search. This in turn in some cases hampered planned cooperation between air search and ground search teams.

The results are summarized in a very simple way in Figure 3. The percentage given is of the total number of possible findings, i.e. the number of sources times the number of teams looking for them. The number is corrected for if teams have not been in certain areas.

The number of possible findings was for AGS 150 and for CGS 432. In practise the possible number of findings for the AGS-teams is less than 150, due to the fact that some sources were arranged in such a way that they should not be seen from the air.

It is necessary to use spectrometric equipment to identify nuclides. It seems to be hard and time consuming to estimate the source activity and no one of the air teams has managed to do it. Good knowledge of parameters like dose rates, distance and thickness of shields is necessary, something you do not have in aerial search. Car search teams that have been successful in estimating the activity have used a combination of methods to gain knowledge of these parameters. One can use dose rate meters to estimate the distance to the source by using the inverse square law. By analysing the relation between the photo peak and the Compton continuum in a gamma energy spectrum you can get some idea of the thickness of the shield.

Car search teams have reported that sources were found with other methods than based on measuring radiation. In same cases the team had information from their flying team and some teams looked for other signs than radiation like white poles or suspicious buildings. So the fact that a source is reported as found does not necessarily mean that something can be said about the effectiveness of the equipment used.

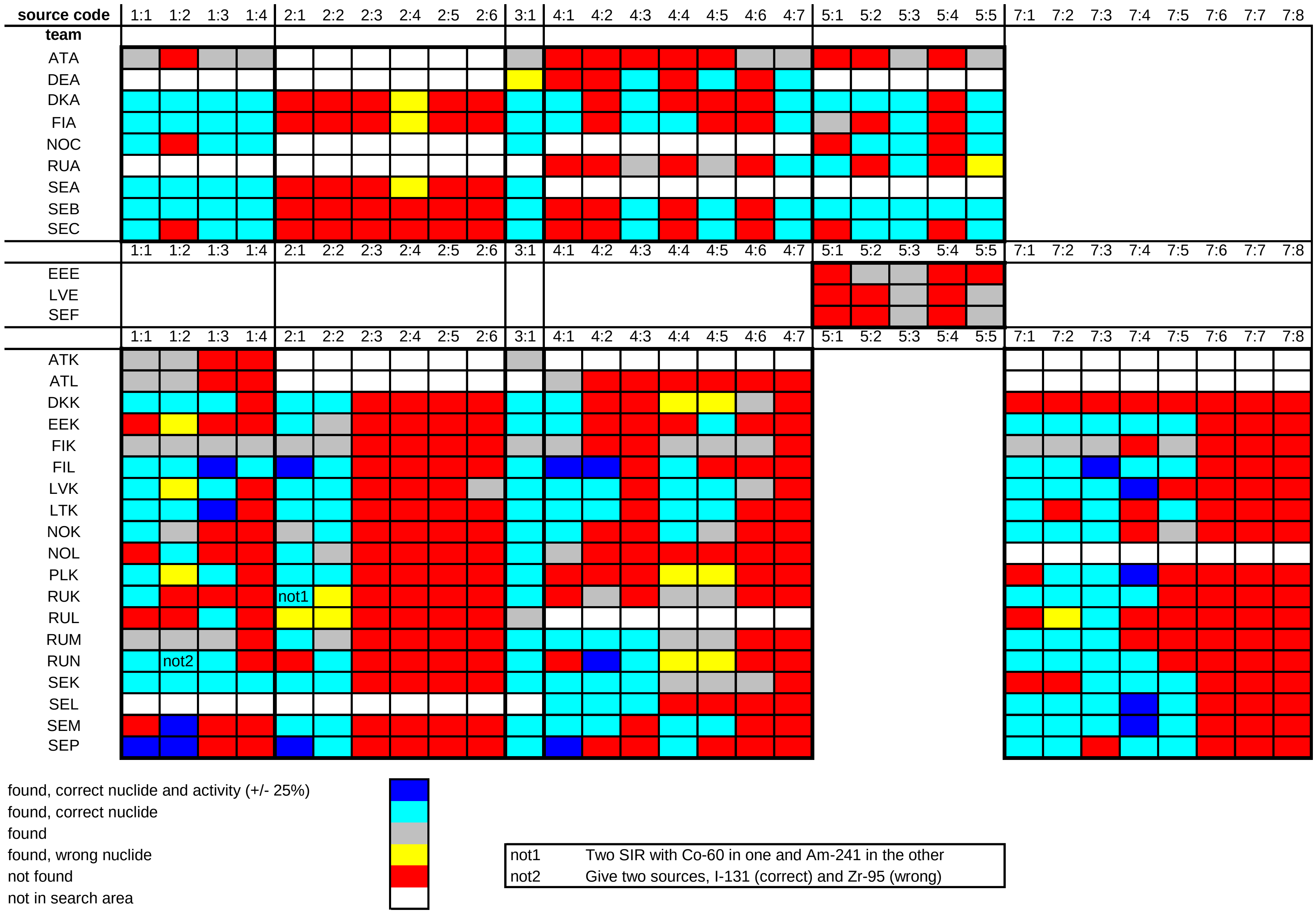
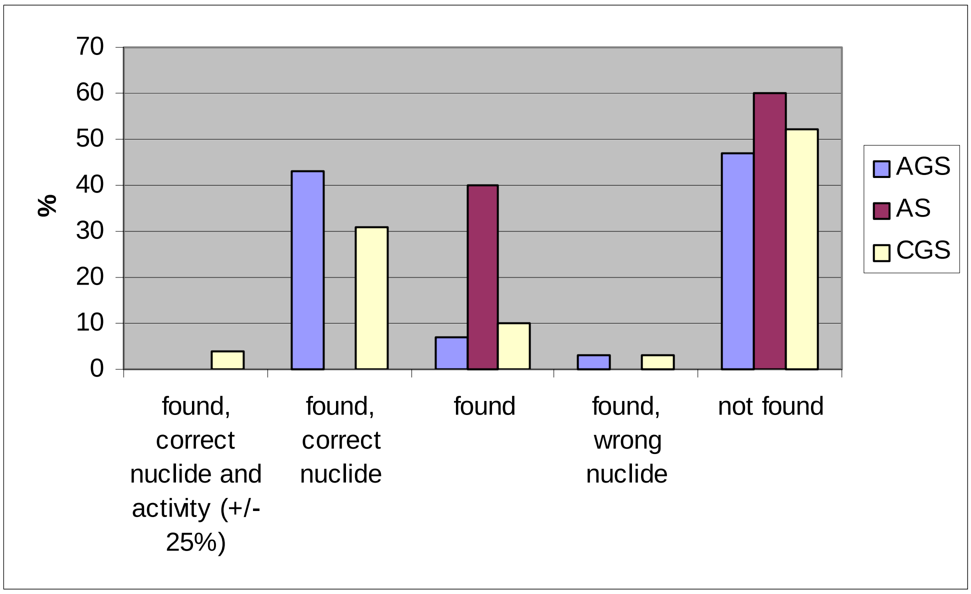


Figure 2. Search results.



AGS	Air Gamma Search
AS	Air Search (with simple equipment, like dose rate meters)
CGS	Car gamma Search

Figure 3. Search results, fractions of sources found.

A more detailed and systematic analysis of by which method and equipment sources were found, can tell whether large detectors give better results than small detectors, or if one detector system or method is better than another. This can be an issue for future work to improve preparedness against radiological accidents.

The "twin sources" 2:1 / 2:2 and 4:4 / 4:5 were placed close together. It can be noticed that in several cases just one of them was reported. For air search it is understandable that it is difficult to separate two sources of the same kind. Car search teams, however, should have a search strategy that ensures that if sources are placed close together, one notice that there is more than one.

Just as it was planned some sources that were found by car search did not turn up in air search reports and vice versa. This is important knowledge in a preparedness point of view, to find all sources you must use complementary search methods.

The weakest source that was found from the air was 4:1, a 0.4 GBq Cs-137 source. Two out of seven teams reported it. The source with the strongest output was 5:1, a 40 Gbq Co-60-source, with just a slightly better result. The output from this source is around 400 times the output from the weaker source, but it was buried to give mainly scattered radiation. Maybe there is a need to develop methods to evaluate scattered radiation too, as a complement to using photo peaks.

There exist many computerised programmes for analysis and presentation of data. An evaluation of their functionality when used by more or less experienced operators, sometimes under stress, could be wise to perform. The fact that different teams and nations use different programmes makes it more difficult to cooperate and exchange data and results, both in research, exercises and accidents.

Session 2

Team reports, Air Gamma Search (AGS)

Austria, team ATA

Austrian Team (ATA)

Wolfgang Fehringer, Federal Ministry of the Interior, Civil Protection School
Andreas Polaschek, Gendarmerie Headquarter of Lower Austria

Team members:

Wolfgang Fehringer, Federal Ministry of the Interior, Civil Protection School
Andreas Polaschek, Gendarmerie Headquarter of Lower Austria
Alois Geyrhofer, Gendarmerie Headquarter of Lower Austria
Gerd Schlager, Police Department of Salzburg
Christian Ebner, Police Department of Salzburg
Wohlgang Klösch, Austrian Research Centers Seiberdorf (ARCS)

Equipment

Portable Air - Car Borne System

Detection system:

- Radiation measuring device SSM1. Time of integration: 5 seconds
- External plastic-scintillator-probe or high-volume Geiger-Müller-probes (Gamma-counter)

Data acquisition and navigation system:

- Rugged military laptop
- Built-in modem and GPS with external antenna
- Mobile power pack

With the built-in modem we can transmit measuring and positioning data to headquarters.

Advantages of the System:

- Short installation time (10 min)
- Simplified handling and data analysis (no experts are necessary)
- Usable for car and helicopter operation
- Online navigation with digital map
- Unlimited operation time (depends on power pack)
- Very rugged system (100% ready for duty) (10 systems are on duty in Austria)

Methods

Airborne gamma search:

- Flying height: 80 m (Barents Rescue - 60 m)
- Speed: 80 km/h
- Line spacing: 100 - 150 m (meander)
- Detector position: on the bottom of the cabin
- Measurement: in counts per second (cps)
- Two officers

One officer takes the seat beneath the pilot and holds the laptop on his knees.

During the flight the pilot can have a look on the screen, where

- the actually position,
- the track,
- the compass-card and
- the count-rate curve

can be seen.

So the pilot in Boden was able to fly a very exact track in the exercise.

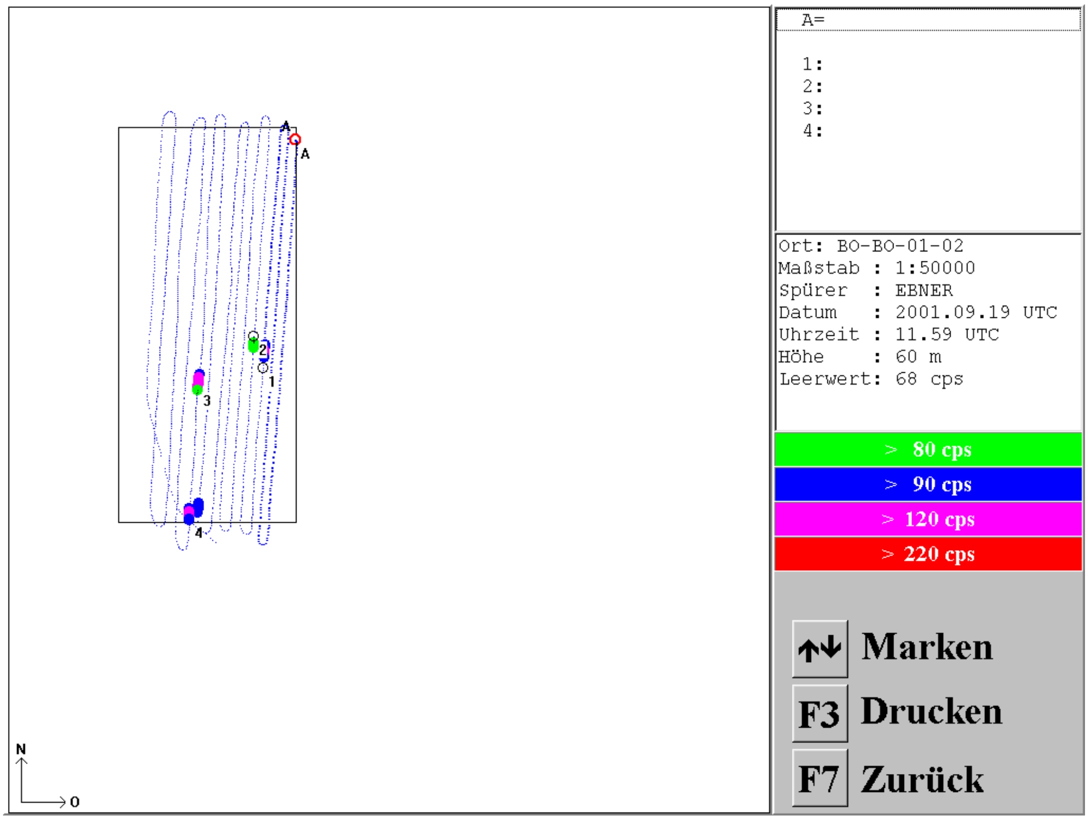
Data analysis

We have got three possibilities to analyse the measuring track:

First a 1:1-overlay for each usable map with four variable count-rate colours to produce a stepped radiation picture:

- File name
- Scale
- Officer
- Date and Time (UTC)
- Height
- Countrate of the background (starting point)

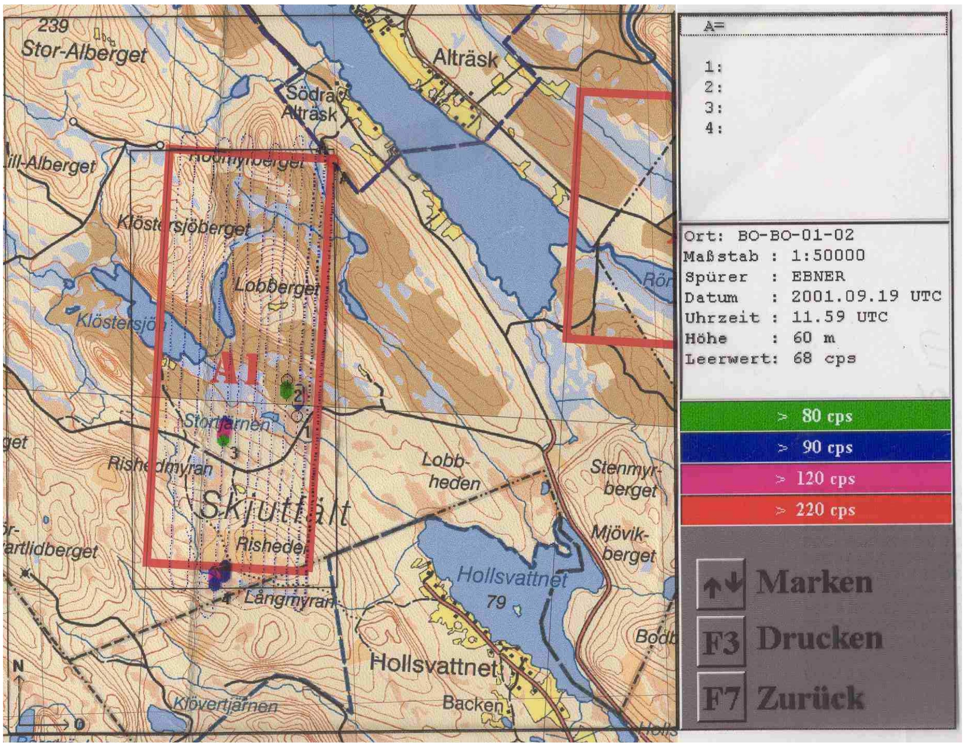
Analysis without digital map (area A1)



Here you can see the exact work of the Swedish pilot whom we have got.

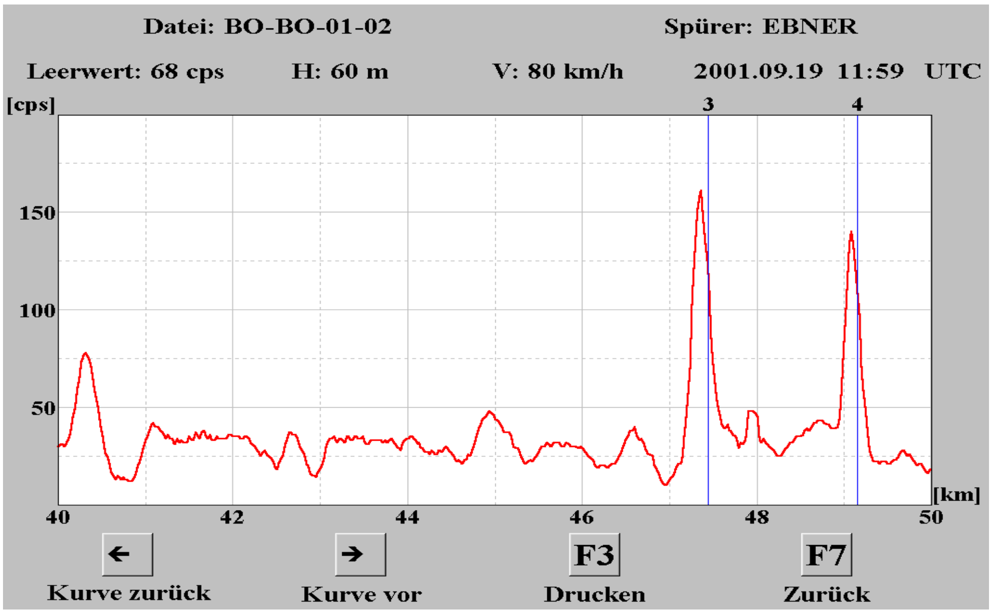
Now we have got the proof, that we can put our equipment in any helicopter and co-operate with pilots, who never have done this work before. A great independence for our system.

Analysis with digital map (area A1)



The second possibility to analyse is the count-rate curve with distance in km:

Counts per second depend on distance (area A1)



The third analysis with the table consists of:

- count-rate
- position data in WGS84-format and in Austria additional in our national format
- both is saved each second

Table evaluation:

Lfd. Nr.	Marke	MW >1000 cps	GPS - Koordinaten WGS 84 Format	Bundesmeldenetz Koordinaten	Blatt Nr.	Bezeichnung
0	A		N51°19.9847´E30°8.3556´			....
871		1168	N51°23.0408´E30°4.6125´			
872		1230	N51°23.0510´E30°4.6129´			
873		1338	N51°23.0510´E30°4.6129´			
874		1477	N51°23.0612´E30°4.6132´			
875		1611	N51°23.0612´E30°4.6132´			
876		1721	N51°23.0715´E30°4.6135´			
877		1749	N51°23.0715´E30°4.6135´			
878		1796	N51°23.0767´E30°4.6136´			
879		1904	N51°23.0871´E30°4.6139´			
880		1968	N51°23.0871´E30°4.6139´			
881		2023	N51°23.0922´E30°4.6140´			
882		2093	N51°23.1024´E30°4.6148´			
883		2166	N51°23.1024´E30°4.6148´			
884		2184	N51°23.1129´E30°4.6152´			
885		2047	N51°23.1129´E30°4.6152´			
886		1865	N51°23.1234´E30°4.6154´			
887		1758	N51°23.1234´E30°4.6154´			
888		1755	N51°23.1285´E30°4.6155´			

```
Ort: C-C-04-01
Spürer      : POL
Datum       : 1999.09.16 UTC
Uhrzeit     : 06.58 UTC
Leerwert    : 43 cps
Max. Wert   : 2184 cps
Höhe        : 0 m
```

↑↓ Tabelle Auf - Ab

F3 Drucken

F7 Zurück

Results

Area A1:

3 of 4 sources have been detected by helicopter

Area A2:

For this area we are not able to present any results because we did no measurements there

Area A3:

The only one source in this area has been detected by helicopter

Area A4:

3 of 7 sources have been detected by helicopter (flight has been stopped because of the weather situation)

Area A5 :

4 of 5 sources have been detected by helicopter

Conclusions

During this exercise we got a lot of practise to take measurements in an area with a high and very different radioactive background.

We met many nice and very helpful people who gave us assistance during this exercise. We really enjoyed our stay in Sweden.

The main advantage of our system is the really short time for being ready to make measurements (about 10 minutes). Although we only can inform the headquarters about the difference to the count rate of the background it is a very useful and important information for urgent decision-finding in the field of radiation protection.

Denmark, team DKA

Danish Team DKA

Kim Bargholz, Frank Andersen,
Danish Emergency Management Agency, Nuclear Safety Division

LOS, PEV, and Træholt; Danish Army

Equipment

The Danish Team DKA uses standard detectors and spectrometers manufactured by the Canadian company Exploranium. Installation of the equipment in the Fennec helicopter, operated by the Danish Army, is performed using special designed mounting equipment. In this way the two Danish AGS systems can be installed in all Fennec helicopters operated by the Danish Army i.e. in total 12 helicopters. The equipment used for the two Danish AGS systems consists of:

- AS-550 Fennec helicopter
- Exploranium GPX-1024 16 L NaI(Tl) detector
- Exploranium GR-820 multichannel analyser (512 channels)
- Exploranium PI660 pilot indicator
- Differential GPS
- Radar altimeter
- Pentium PC with Windows 98
- Special designed soft ware

Methods

The Danish AGS systems are designed for emergency preparedness purposes i.e. the systems should be used for fast mapping of the contamination levels on the ground after an accident involving radioactive material. However, searching for orphan sources can be done using the same equipment and methods as for mapping of ground level contamination levels.

Usually, flight lines going north to south or west to east is planned with a certain line spacing depending on the type of measurements that should be performed. During the search for orphan sources at the LIVEX exercise 100-meter line spacing was chosen. The areas to be surveyed were 2 by 5 km of size resulting in 21 lines going north to south. The speed during the measurements was initially set to approximately 150 km/h. However, due to the limited time for survey in each area the speed had to be increased to approximately 170-180 km/h in order to cover the whole area with a line spacing of 100 meter. During all flights the altitude was 60 meter AGL.

As an example of the actual flight lines Figure 1 shows the lines flown in area A1 during the exercise. Due to the pilot indicator it is possible to perform actual flight lines that are close to the planned lines. The pilot indicator at all times shows the pilot how many meters the helicopter is of track both horizontally and vertically. Consequently the pilot can adjust the actual track so it matches the planned track within a difference of no more than 10-20 meters.

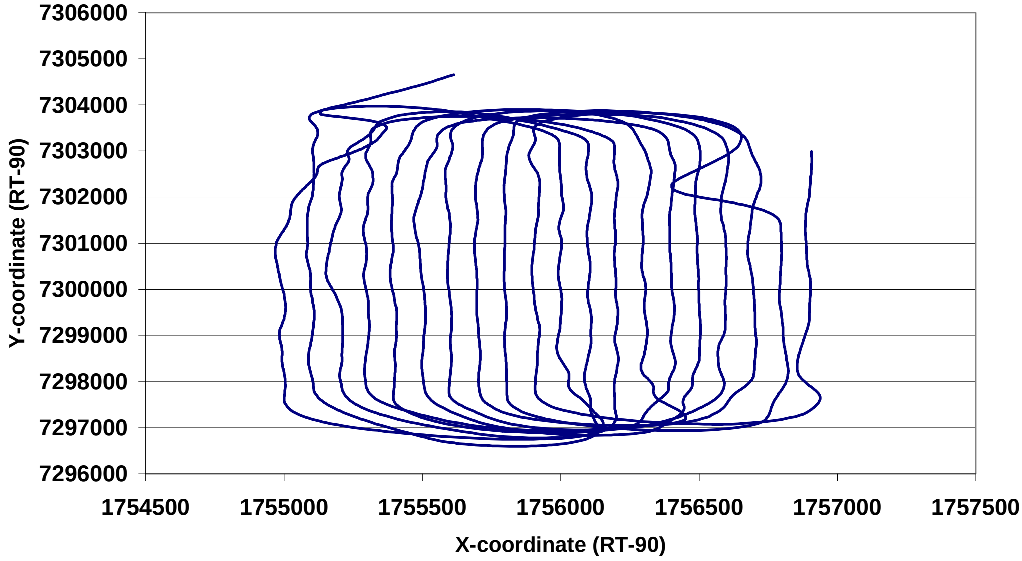


Figure 1: Actual flight lines at area A1 performed by DKA

During a survey the Danish airborne system measures one spectrum per second together with altitude read from the radar altimeter and the position determined by the DGPS system. All data obtained every second are stored as binary files that can be processed afterwards. Online data processing is not included in the Danish system. As the system is a emergency preparedness system that in accident situation is operated by non-experts the system should be as simple as possible in order to ensure that the system is operated correct.

Data analysis

To process large series of data from e.g. AGS systems DEMA has developed a Windows NT/2000 data processing tool called NUCSpec (Ref 2). NUCSpec is capable of viewing the large data files in an easy way using the 'waterfall' technique and processing the data using both the standard techniques and more advanced methods such as NASVD.

When a data file is opened in NUCSpec the active window is divided into 4 different views - two spectrum views (upper and lower) and two information views (upper and lower). Figure 2 shows the NUCSpec layout when a data file is open.

Upper spectrum view

The upper spectrum view shows a large number of spectra. The total number of spectra viewed depends on the size of the window. Each spectrum is shown as horizontal pixel-lines, with each line representing a spectrum (512 or 256 channels) with different pixel colours indicating different numbers of counts. A red pixel may represent channel counts around 100 counts, whereas a blue pixel could represent channel counts around 10. The colour scale can be changed by use of the colour set-up menu in the set-up pull down menu.

In this way a large number of spectra can easily be viewed on the screen together as colour lines, and as the human eye easily detects gradients in colours it is easily discovered when (even minor) spectrum changes occur. By use of the scroll bars in the upper spectrum view it is possible to sweep back and forth (in time) through the data file in order to find spectra of peculiar appearance.

Lower spectrum view

The lower view shows the spectrum pointed at by the arrow in the upper spectrum view. The spectrum is shown as an ordinary gamma-spectrum i.e. counts vs. channel number.

Upper information view

Upper information view contains all information related to the spectrum the cursor points at when the upper spectrum field is active. The first line is the spectrum number, which always shows the actual spectrum number pointed at (the series of spectra are numbered beginning with zero). The time shown is the UTC time determined from the GPS or the computer system. The coordinates shown (N,E) are determined by GPS/DGPS measurements. Live time and real time is shown for each measurement and the altitude is shown if it is measured and included in the data file. The **Window Cnt** is the count rate of a user-defined region of interest (user defined window).

Lower information view

The lower information view contains information similar to the upper information view. However, the information is related to the spectrum shown on the lower spectrum view i.e. the spectrum pointed at by the arrow to the left in the upper spectrum view.

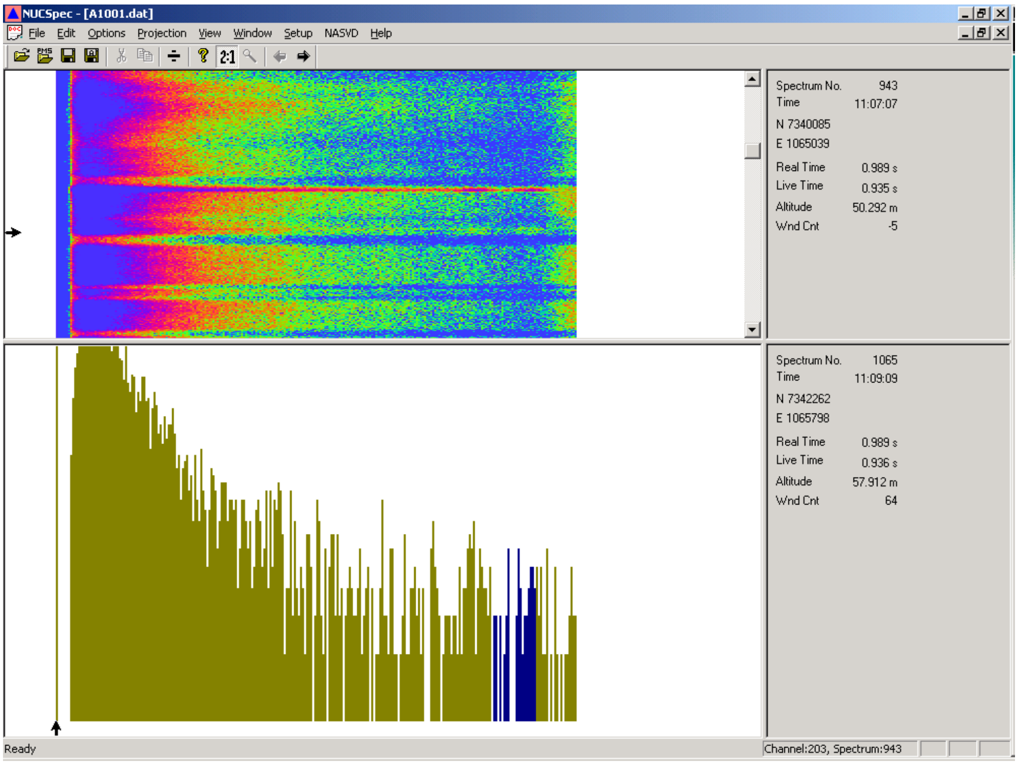


Figure 2: Layout of NUCSpec with an open data file (only channel 1-256)

Using NUCSpec, standard processing of the data is possible, such as the windows method (stripping), conversion of stripped count rates to ground level concentrations, altitude corrections, dose rate calculations using the Spectrum Dose Index (SDI) method, extended windows method for calculation of Cs concentrations. Projections can be chosen from a user defined range of different coordinate systems including the Swedish RT90 system.

However, at the LIVEX exercise the Noise Adjusting Singular Value Decomposition (NASVD) was primarily used for processing the data and to identify positions of orphan sources.

NASVD is a method developed for processing spectral data series (Ref 1). The method determines a set of spectral components that in linear combination can describe each measured spectrum from the data series.

1. The first component is the average of all spectra. It is termed spectral component S0.
2. The second component (termed S1) is determined, so linear combinations of S0 and S1 can describe all spectra in the best way with only the two components.
3. The third component (termed S2) is determined so it in combination with S0 and S1 can describe all spectra in the data series in the best way with only three components.
4. The fourth component (termed S3) is determined so it in combination with the three first components can describe all spectra in the best way.
5. The fifth component (termed S4) etc.

Based on the spectral components it is possible to identify different kinds of radioactive isotopes that have been present in the area surveyed. As an example the data obtained from area A1 can be used. Spectral component No.3 is shown in Figure 3.

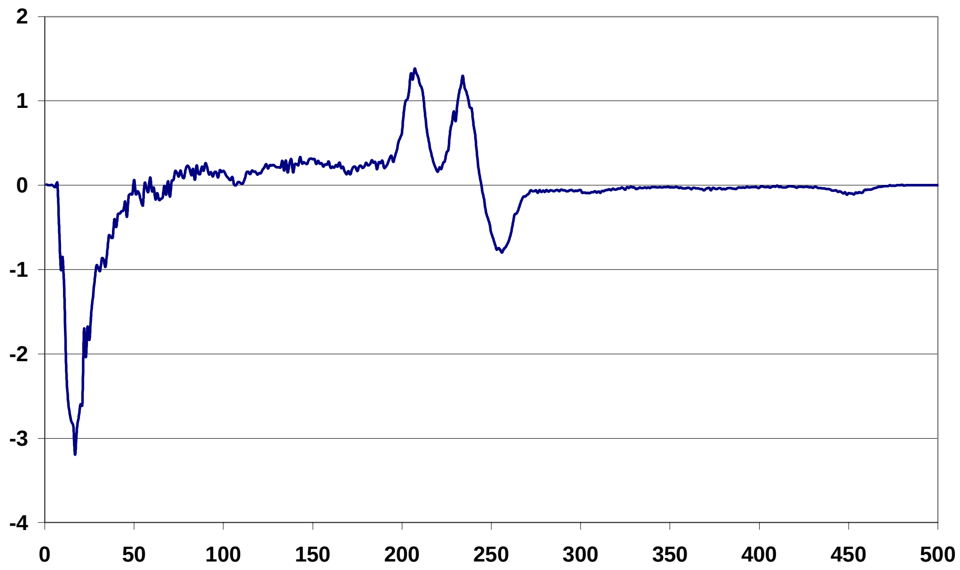


Figure 3: Spectral component No 3 obtained from NASVD processing of the data from area A1

As seen from Figure 3 the spectral shape is clearly caused by Co-60 present in the area. Based on this component it possible to identify the places where Co-60 has been present looking at the concentration of the component in each spectrum in the data series.

In case of more than one isotope present in the area other components would show this as typical spectral shapes for that specific isotopes.

In Figure 4 the concentration of spectral component No 3 obtained from NASVD processing the data from area A1 are shown. In total approximately 3800 spectra were measured in area A1.

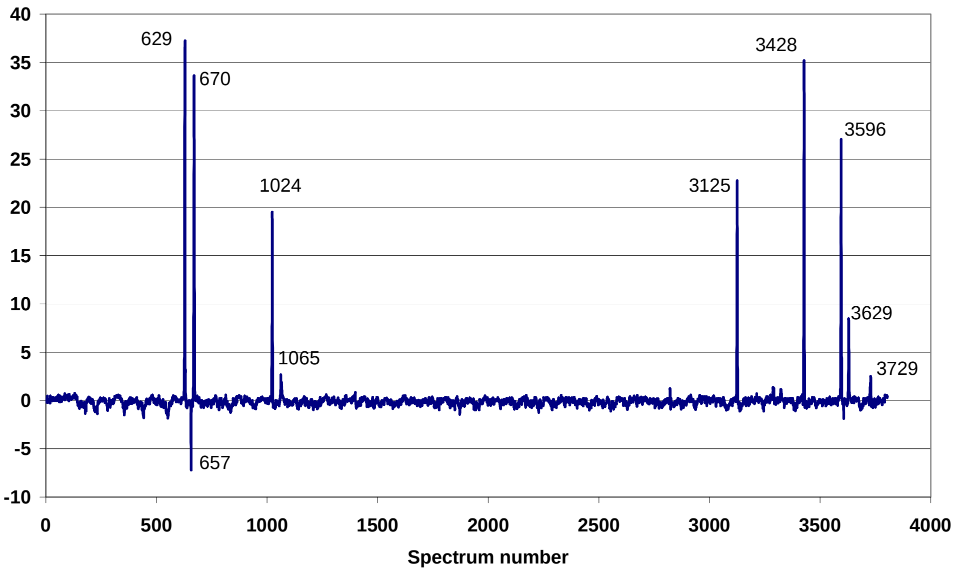


Figure 4: Concentration of spectral component No 3 in the data series measured in area A1

In Figure 4, it can be observed that spectral component No. 3 contributes to spectrum No. 1024 and No. 1065. It is seen that the contribution is larger in spectrum No 1024 than in spectrum No. 1065. This is also clearly seen from Figure 3 where spectrum No. 1065 is shown in the lower spectrum view. It is obvious looking at Figure 3 that Co-60 (spectral component No 3) is present in spectrum No. 1024 whereas the contribution in spectrum No 1065 is hard to recognize.

Reconstruction of the spectral data series using the spectral components from the NASVD processing can remove the noise in the spectra if only the components with ‘real’ spectral shapes are included. In Figure 5 the reconstructed spectra is shown.

After reconstruction it is observed that the Co-60 signal both at spectrum No 1024 and spectrum No 1065 is easily seen both in upper and lower spectrum view.

In this way possible contribution from orphan sources to the spectral measurements can be identified.

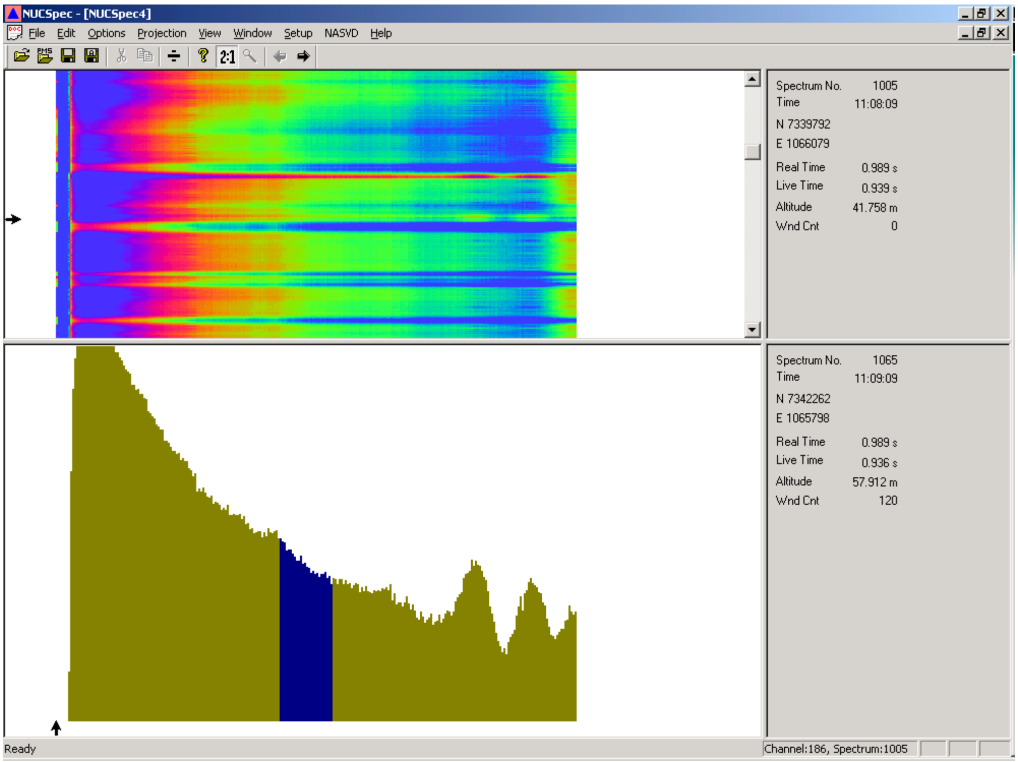


Figure 5: Reconstructed spectra using the NASVD method (only channel 1 to 256 shown)

Results

Within one hour, source identification papers, NKS files, and dose rate maps were delivered to REAC. All results were obtained using the NUCSpec program.

Besides that source identification papers and the NKS files DKA also produced and delivered dose rate maps from the surveyed areas. The dose rate maps were produced using the SDI method (Ref 3) and presented in MapInfo together with geographical maps made available by the Swedish organizers of the exercise.

In Figure 6 the dose rate map covering area A1 is shown. It is clearly seen where the three Co-60 sources are placed and also the Ir-192 source position can be identified. If for example the Co-60 or Ir-192 signal were mapped the positions of the sources would have been even more obvious.

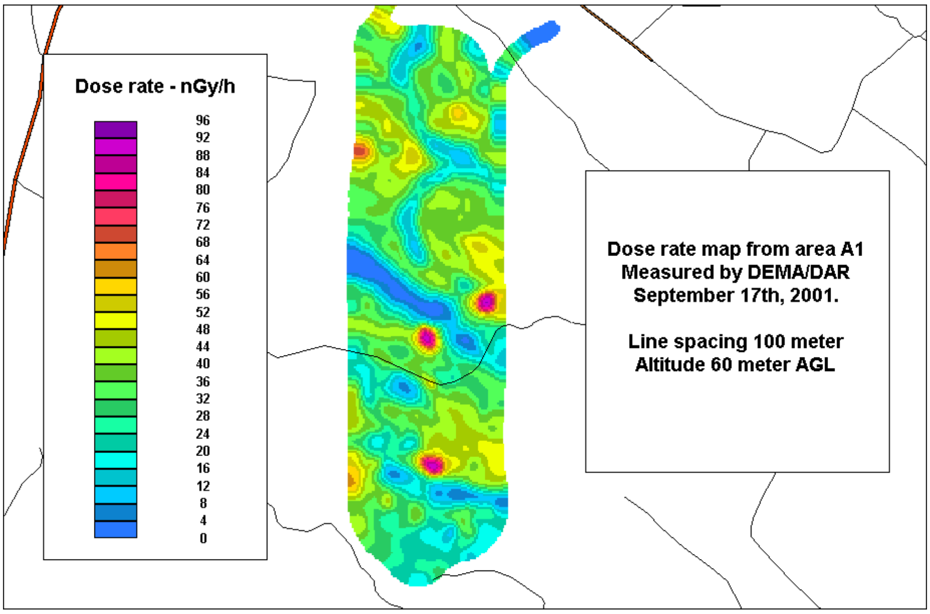


Figure 6: Dose rate map from area A1 determined from DKA measurements

During the exercise DKA succeeded in surveying all 5 areas and also the reference area A6 were surveyed during the pre exercise. The orphan sources identified by DKA in each of the 5 areas are listed in the tables below. Only the type of source and the position of the source were reported. No attempt was made to estimate the source strength. The source strength estimation will always depend on a lot of assumptions on shielding etc and therefore always including a large uncertainty. Looking from an emergency preparedness point of view the main goal is to identify the position of a possible orphan source and the type of source. The precise strength should be determined from ground level measurements at the coordinate given by the airborne team.

Sources identification results from area A1 by DKA				
Nuclide	**Code**	**Position**	**Reported position**	**Comments**
Co-60	1:1	1756005 7298134	1756100 7298100	Reported correctly by DKA
I-131	1:2	1756005 7299224	1755920 7299267	Reported correctly by DKA
Co-60	1:3	1755956 7299830	1756000 7299900	Reported correctly by DKA
Co-60	1:4	1756747 7300334	1756800 7300300	Reported correctly by DKA

Sources identification results from area A2 by DKA				
Nuclide	**Code**	**Position**	**Reported position**	**Comments**
Co-60	2:1	1764029 7307246		Not found – placed inside concrete bunker
Co-60	2:2	1764048 7307266		Not found – placed inside concrete bunker
Mo-99	2:3	1764844 7307031		Not found
Mo-99	2:4	1765350 7305451	1765387 7305419	Reported by DKA but identified as Tc-99
Cs-137	2:5-1	1763466 7306095		Not found – weak source directed upwards
Co-60	2:5-2	1763466 7306095		Not found – weak source directed SW

Sources identification results from area A3 by DKA				
Nuclide	**Code**	**Position**	**Reported position**	**Comments**
Co-60	3:1	1766304 7316848	1766274 7316825	Reported correctly by DKA

Sources identification results from area A4 by DKA				
Nuclide	**Code**	**Position**	**Reported position**	**Comments**
Cs-137	4:1	1760923 7321390	1760912 7321349	Reported correctly by DKA
Cs-137	4:2	1760488 7323895		Not found – placed in a birdhouse, shielded upwards
Ir-192	4:3	1760310 7323933	1760326 7323952	Reported correctly by DKA
Co-60	4:4	1761137 7323702		Not found – placed in concrete fire trench and covered with steel plate and sand
Co-60	4:5	1761117 7323744		Not found – placed in concrete fire trench and covered with steel plate and sand
Cs-137	4:6	1761442 7323932		Not found – placed in tracked vehicle cart, shielded upwards
Cs-137	4:7	1761559 7323941	1761502 7323985	Reported correctly by DKA

Sources identification results from area A5 by DKA				
Nuclide	**Code**	**Position**	**Reported position**	**Comments**
Co-60	5:1	1756869 7322034	1756897 7322002	Reported correctly by DKA
Cs-137	5:2	1755733 7321627	1755703 7321622	Reported correctly by DKA
Co-60	5:3	1755750 7321686	1755703 7321622	Reported correctly by DKA
Cs-137	5:4	Moving		Not found – moving source
Ir-192	5:5	1756402 7324293	1756489 7324250	Reported correctly by DKA

Conclusions

The Danish airborne team DKA found and identified the sources that could be seen from measurements with AGS. Only one of the sources found was not identified correctly (in area A2 Mo-99 was reported as Tc-99). The sources not found by DKA was either heavily shielded upwards or directed/collimated narrowly i.e. the AGS teams had to fly directly above the narrow beam in order to detect the source if possible.

It was during the exercise proven that the NUCSpec software developed by DEMA is a fast and reliable processing tool for AGS data both for mapping of contamination and for identifying orphan sources. Also production of NKS files and colour coded maps showing the levels of radiation at ground level can be performed fast and reliable.

The exercise also showed that bringing a helicopter from Denmark to neighbouring countries could be done without any problems. In fact bringing the helicopter that the equipment is designed for eliminates many problems connected to installation of the equipment in other aircrafts. Performing flights in e.g. more hilly areas than can be seen in Denmark was also proven to be possible including flight planning using completely different projection as the Swedish RT90 coordinate system.

In general the Danish airborne team found the LIVEX exercise very useful both as a test for carrying out help to neighbouring countries and as a test of our own ability to perform airborne surveys in different areas than can be seen in Denmark.

Acronyms

DEMA – Danish Emergency Management Agency

DAR – Danish Army

DKA – Danish airborne team No. A

NASVD – Noise Adjusted Singular Value Decomposition

AGS – Airborne Gamma-Ray Spectrometry

SDI – Spectrum Dose Index

References

1. Hovgaard, J., “Airborne Gamma-ray Spectrometry. Statistical Analysis of Airborne Gamma-ray Spectra”, DTU, IAU Ph.D. Thesis, October 1997.
2. Bargholz, K., “NUCSpec manual version 2.0”, Danish Emergency Management Agency, Nuclear Safety Division, 2000.
3. Bargholz, K., “Dose rate and nuclide mapping from airborne and ground based gamma-ray instrumentation”, DTU, IAU Ph.D. Thesis, April 2001.

Finland, team FIA

Finnish Team (FIA)

Markku Kettunen

Team members:

Mika Nikkinen
Tapio Heininen
Kari Keskitalo
Anita Pippuri
Juha Brander

Equipment

6x4 inch NaI detector + MicroNomad analyzer

70% HPGe detector + DART analyzer

GPS GLONASS satellite navigator

Three IBM ThinkPad laptop computers

DC/AC –inverter

The above instruments were installed in a Swedish civilian helicopter (Eurocopter 350), which was furnished by the organizer of the "Barents Rescue 2001" event.

Methods

The helicopter flew continuously over the measurement area at a height of 60 meters. Its speed varied between 150 and 230 km/h. The lines were spaced 100 meters apart. The spectrometers had an integration time of about 1 second. Navigation was primarily based on the GPS and MapPerfect navigation programs. Turns were made inside the measurement area. The aim was to provide coverage that was as uniform as possible for the whole measurement area within the limited flight time.

A back seat was removed from the helicopter, and the detectors were positioned in its place. The detectors were protected against shock and vibration. Their location was chosen to minimize attenuation from incoming radiation. The helicopter body attenuation factor was modelled using point-source measurement.

Data analysis

The online detection of the source was based on the online display of the SAMPO program. Sources were recognized using predefined regions of interest (roi) areas by checking for the sum spectra after the measurement and then processing the data. HPGe and NaI detector data were used to determine both the nuclide and the activity of the orphan source. The SAMPO and GMLINT programs were used for the post-processing. The activity estimate was based on the approximation done by the GMLINT program. All possible shielding was evaluated with the graphics produced by GMLINT.

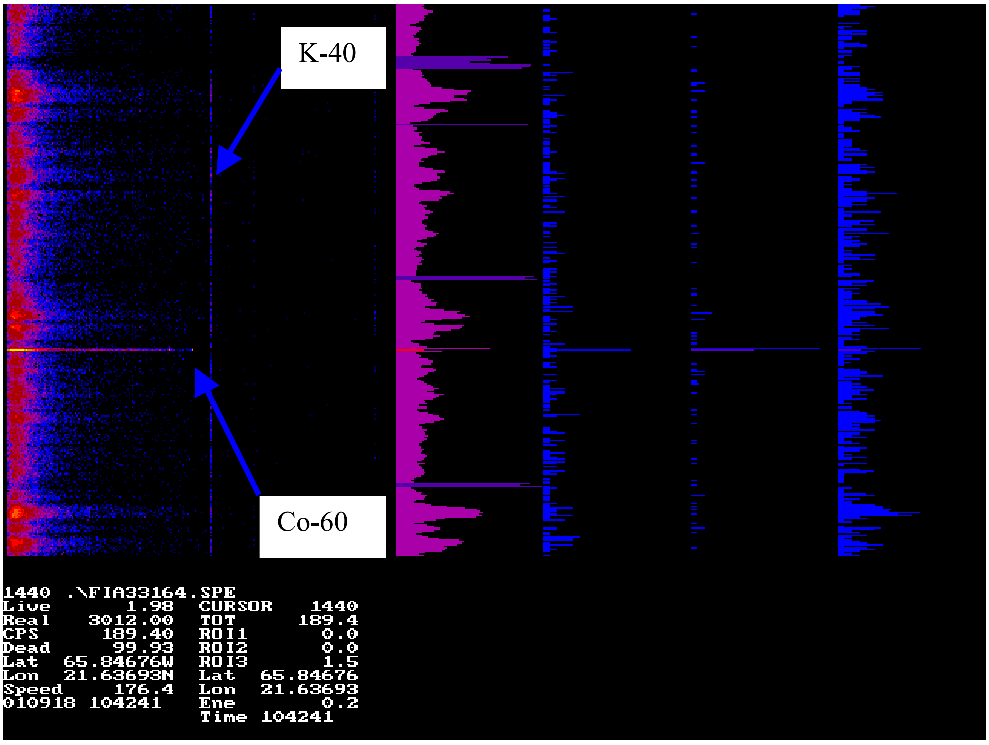


Figure 1. An example of a SAMPO window. The last 360 spectra of the measurement are shown. K-40 can be easily identified and two peaks of Co-60 point sources are visible.

Results

During the exercise, all five measurement-areas were scanned.

Area A1

Found sources:

I-131	21°22'52.68''	65° 41' 29. 60''	3 GBq
Co-60	21°22'48.97''	65° 41' 45. 86'' Open source	1 GBq
Co-60	21°23'54.90''	65° 42' 08. 50'' Open source	1.2 GBq
Co-60	21°22'41.99''	65° 40' 53. 75'' Prop collimated	0.6 GBq
Cs-137	21°23'54.90''	65° 42' 09. 00'' Uncertain	0.25 GBq

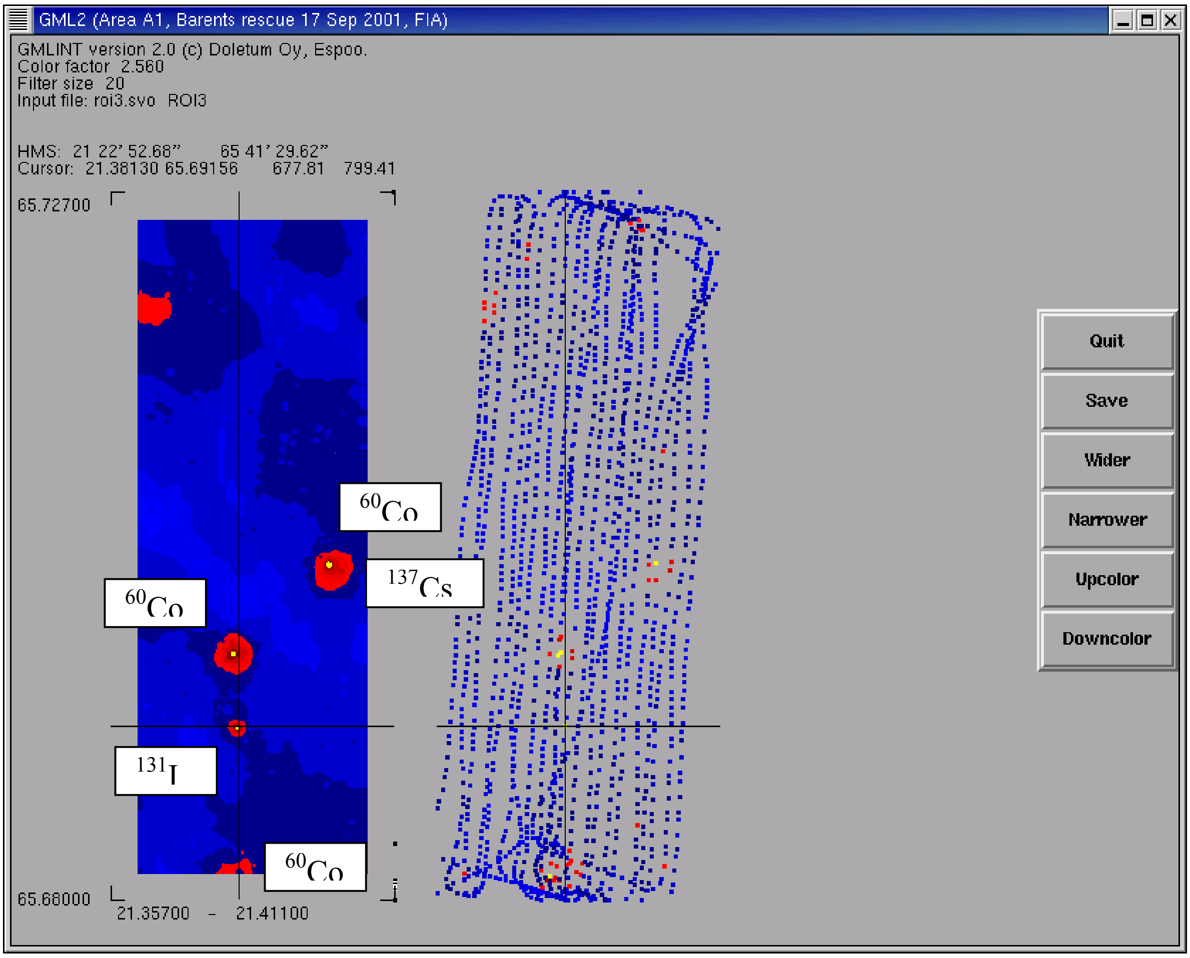


Figure 2. A low-energy window showing both Co-60 and I-131 detections. The red point in the upper left corner is an open top of a hill.

All the A1 sources were found and identified correctly, with one extra Cs-137 source being reported as “not absolutely certain”.

Area A2

Found sources

Cs-137	21°36’33.00’’	65°46’22.80’’	1 GBq
Cs-137	21°35’45.51’’	65°44’26.39’’	0.5 GBq

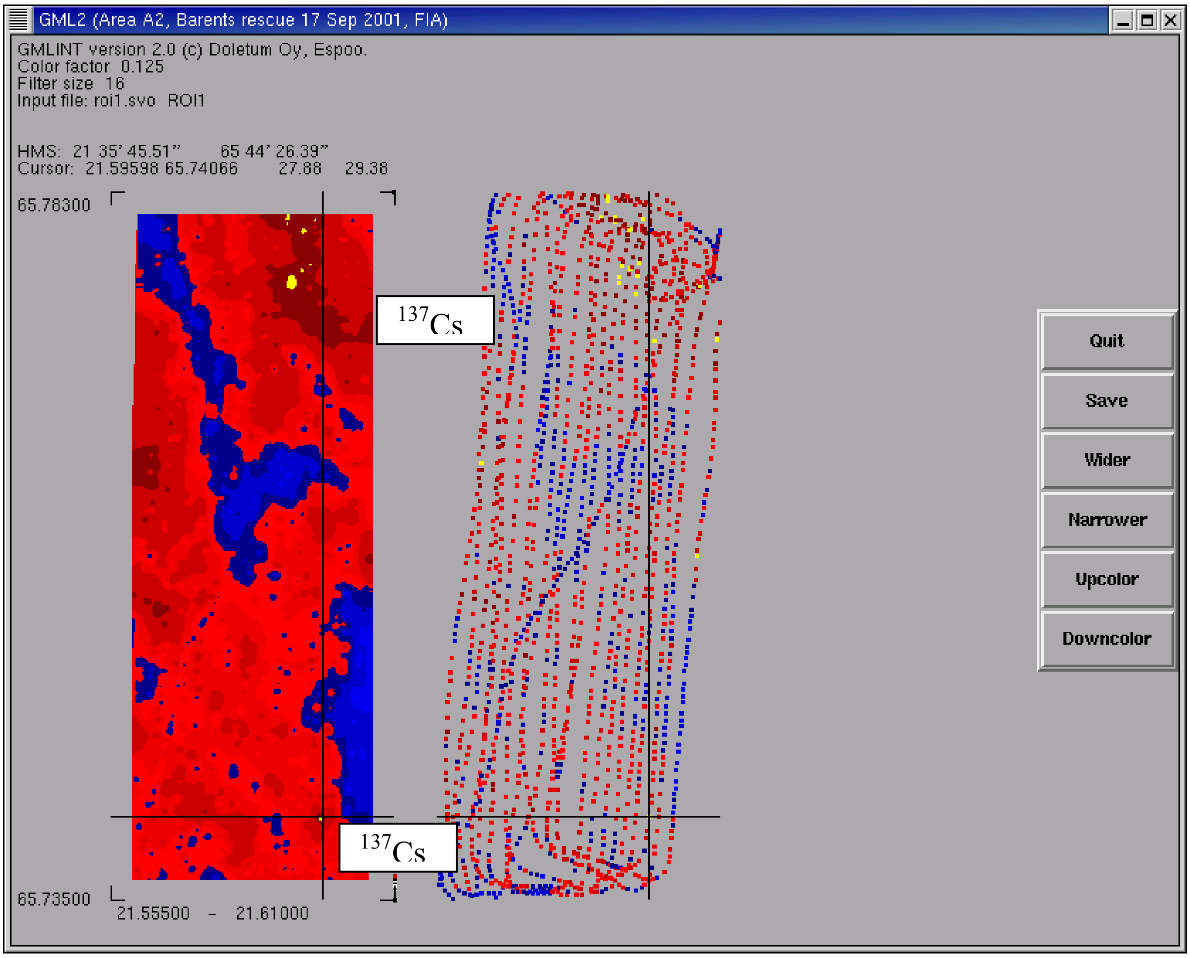


Figure 3. The sources within the area were somewhat uncertain. The upper source was found outside the area. It could also have been scattered radiation due to the hill that was being approached. The lower identified point close to the detection limit.

Five A2 sources were missed, one Mo-99 source being found and reported as Cs-137.

Area A3

Found sources:

Co-60	65°50'28.61"	21°38'26.16"	2.5 GBq
-	65°51'33.12"	21°39'19.0	

Fortress, added for car teams for further checking

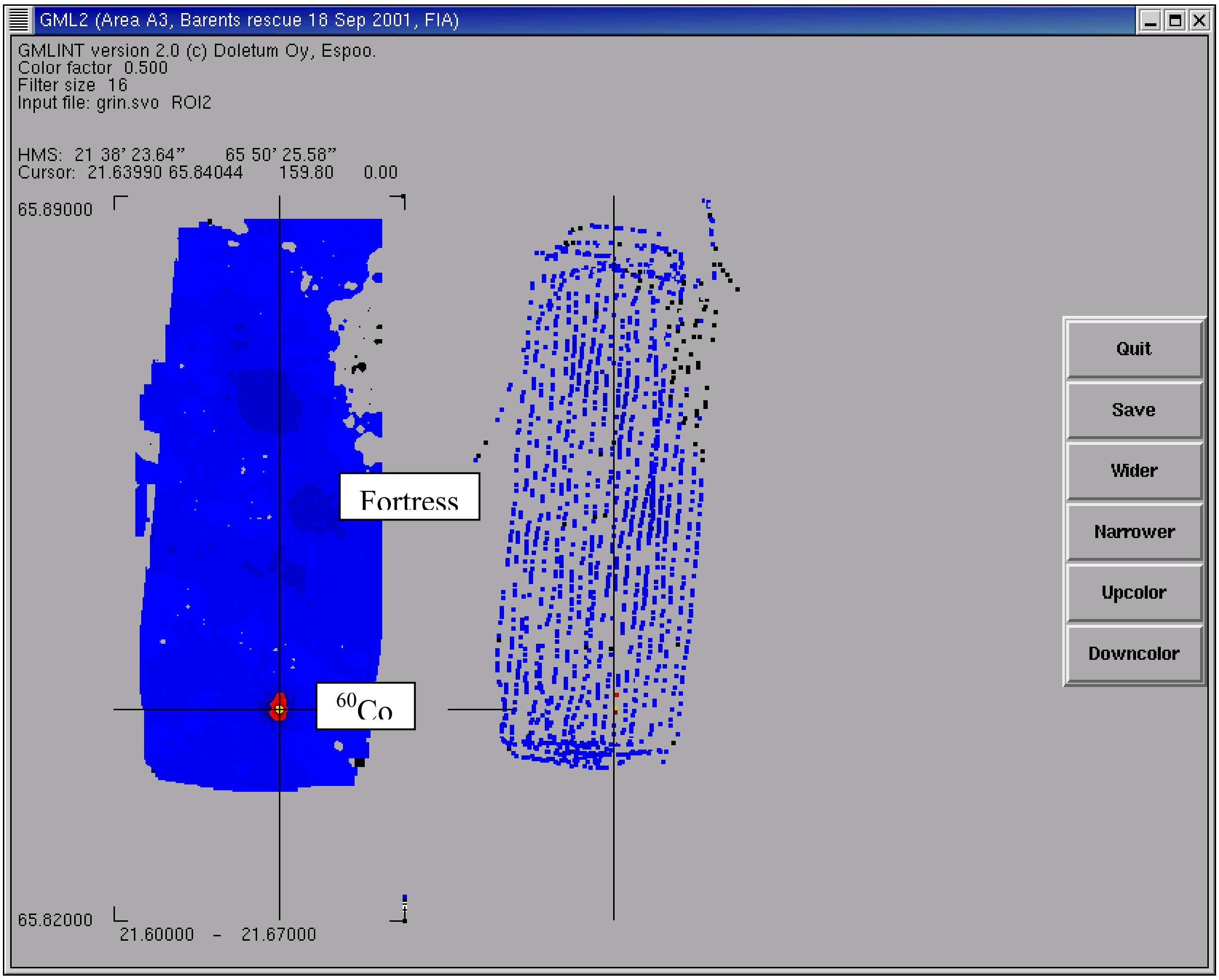


Figure 4. Co-60 map of the area, with one clear source visible. The fortress on the top of the hill produced a higher count rate. There may have been a source inside the building or the count rate may have been higher due to the K-40 found in the concrete.

An A3 Co-60 source was correctly found, and a bunker was checked as a possible hidden source.

Area A4

Found sources:

Ir-192	65°54’30.39”	21°31’23.16”	2.7 GBq
Co-60	65°54’21.31”	21°32’26.16”	0.3 GBq
Cs-137	65°54’30.39”	21°33’01.44”	0.8 GBq
Cs-137	65°53’10.75”	21°31’54.40”	0.5 GBq

Apparent activity, prob. collimated

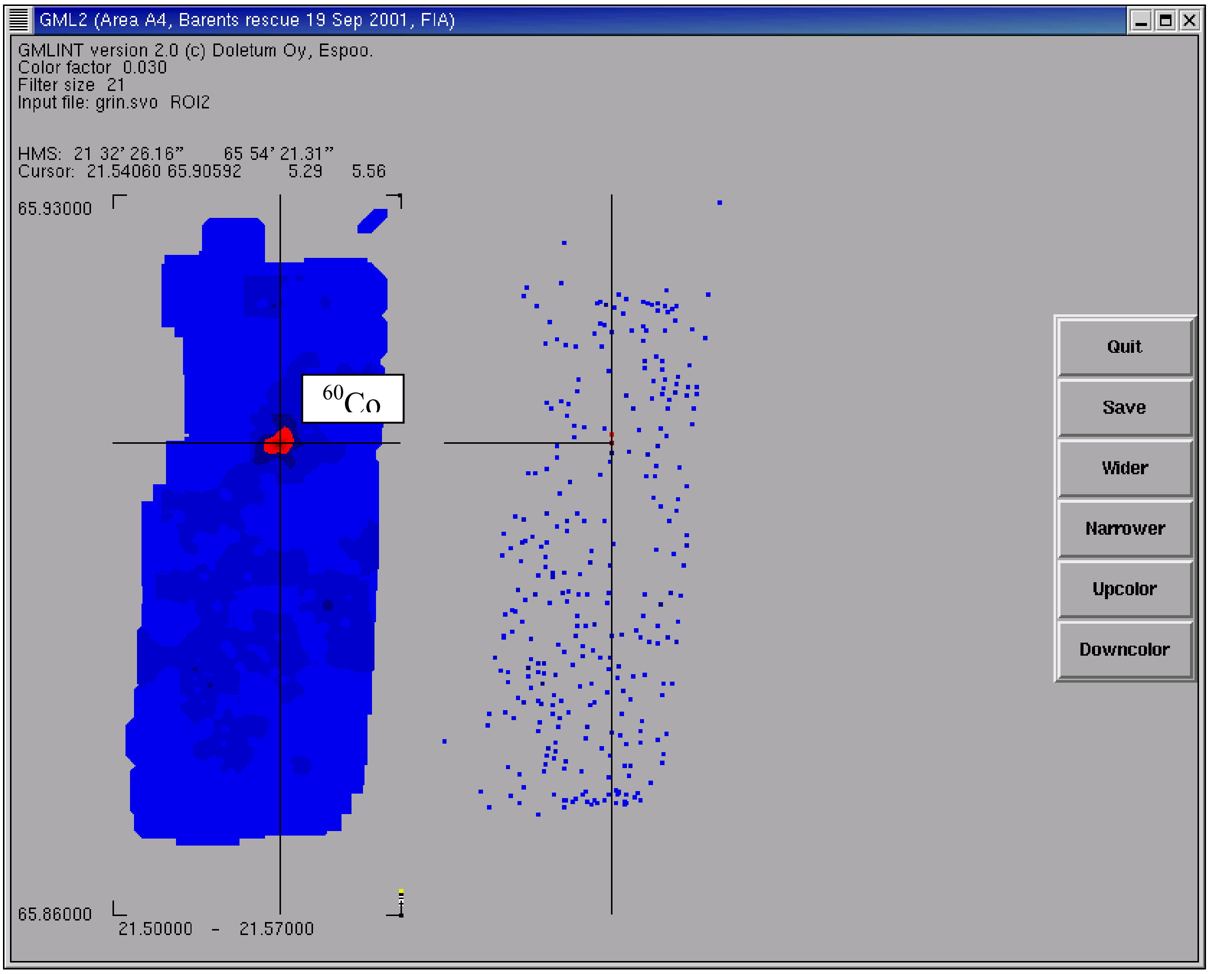


Figure 5. A Co-60 map of the area, with one clear source being visible.

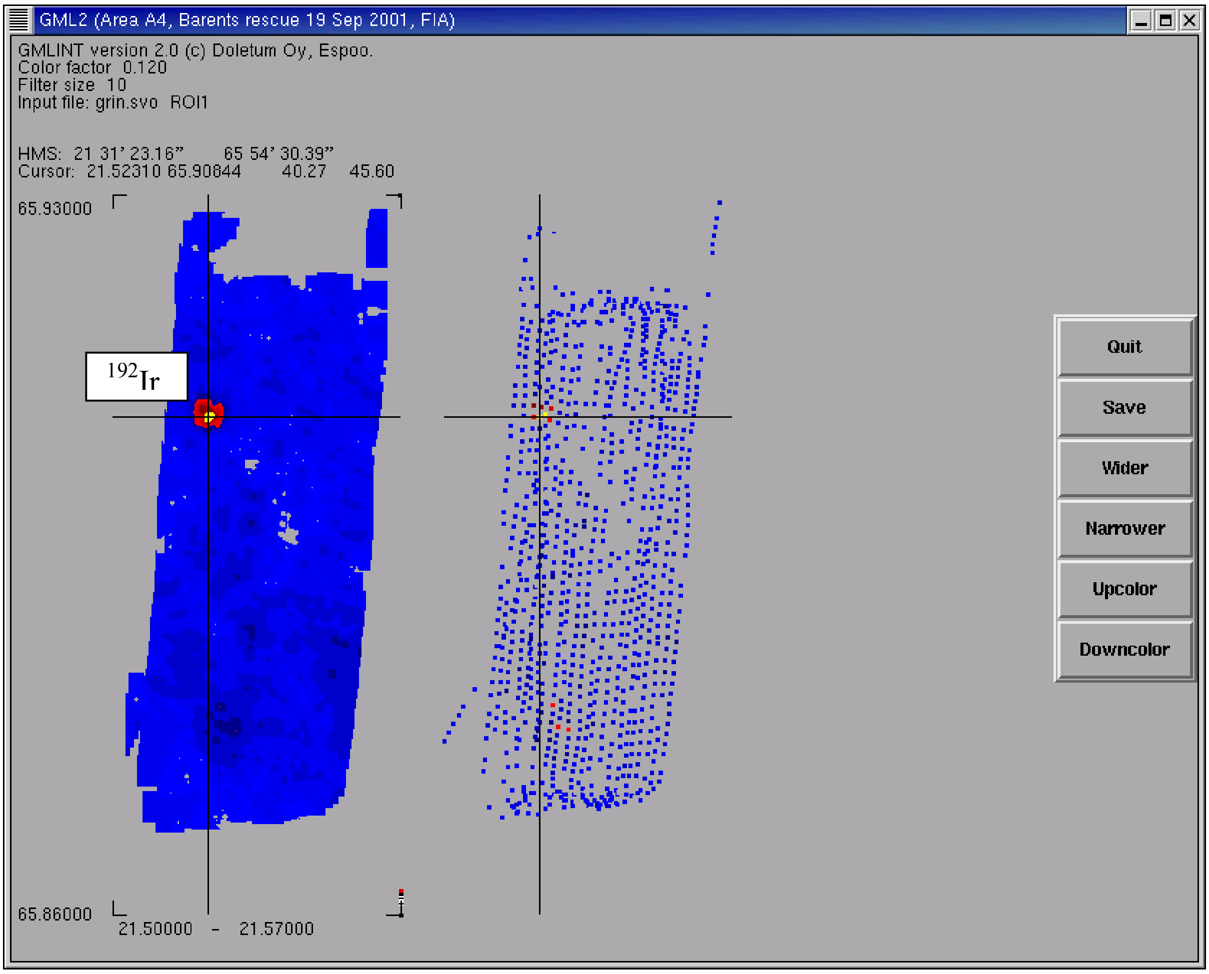


Figure 6. Total counts for area 4. One Ir-192 source is clearly visible.

Four A4 sources were found and identified correctly.

Area A5

Found sources:

Co-60	65°53'34.79"	21°25'11.10"	2 GBq
Ir-192	65°54'55.94"	21°26'26.70"	2.9 GBq
-	65°53'42.86"	21°26'39.30"	Uncertain, added for car teams for further checking

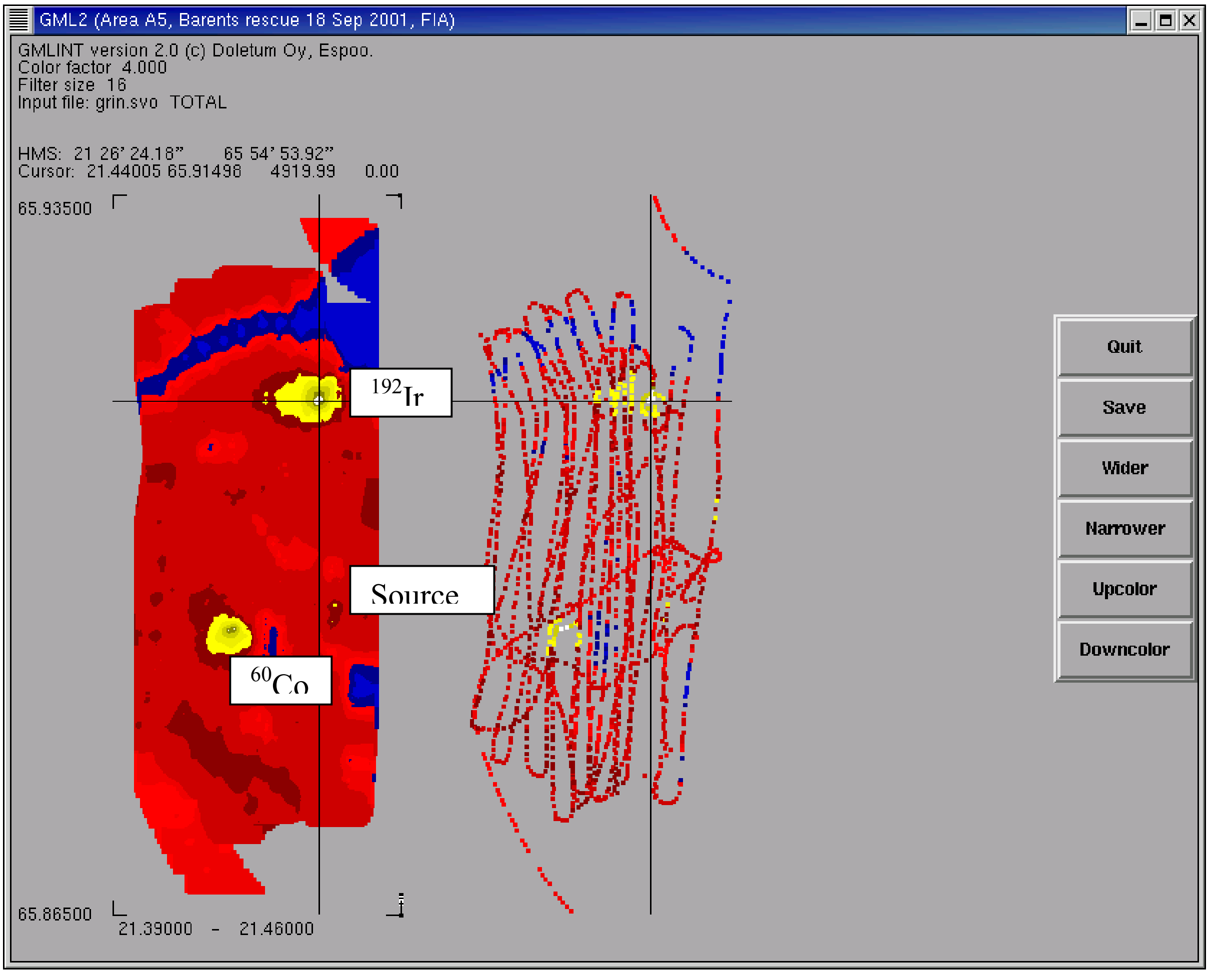


Figure 7. Total counts found in area 5. Two strong sources were clearly visible, one additional high count, a "hot spot", was added for further inspection by the car teams. The flight lines were selected according to visual navigation.

Three A5 sources were found, and two were identified correctly.

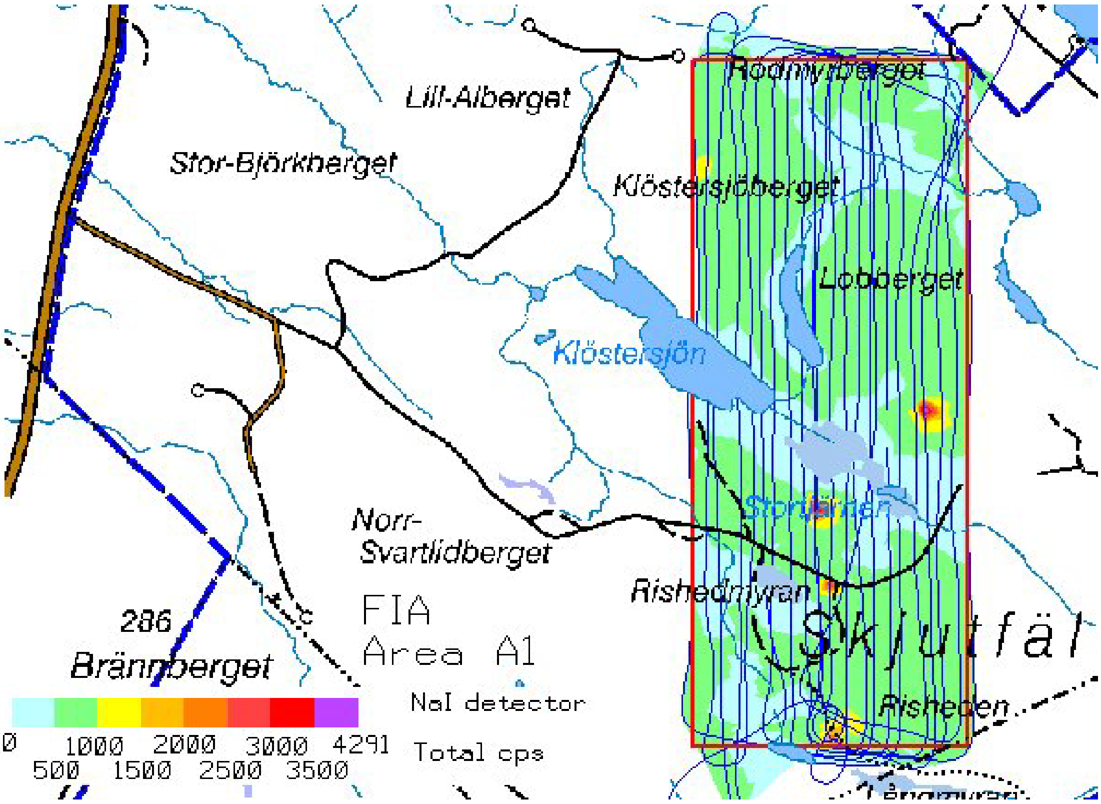


Figure. 8. The results of the measurements and the flight path can be plotted on the map in real time when computers are connected by the PC network. This map was produced after the measurements had been made.

Conclusions

The good spectral quality of the rather small detectors allowed most of the hidden sources to be found using the advanced post-processing technique. Altogether 13 of the 23 hidden sources were revealed.

Acronyms

Airborne radiation measurements, for locating lost point sources.

References

Kettunen, M.J., Heininen, T.J., Pulakka, M. Finland's defence forces preparedness to make airborne gamma measurement in emergency situation. In: NBC 2000 Symposium on Nuclear, Biological and Chemical Threats in the 21st century, Jyväskylä, Finland 2000. ISBN 951-39-0591-8.

Nikkinen, M.T., Kettunen M.J., Toivonen, H.I.K., Mobile radiation monitoring using Gammaspectrometers. Paper presented at the Symposium on International Safeguards, International Atomic Energy Agency, Vienna, Austria 13-17 October 1997.

Germany, team DEA

The German AGS team (DEA)

Airborne measurements of hidden radioactive sources

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The German aerogamma team of the Federal Office for Radiation Protection (BfS) and the Federal Border Police (BGS) participated in the „Barents Rescue Exercise 2001" in Boden (Sweden). We particularly took part in the „Gamma Search Cell" which was integrated within the „Joint Field Exercises". The aims of the airborne measurements were the localization and mapping of artificial sources and the determination of their activities.

We used a high purity germanium-semiconductor detector with a relative efficiency of 50 % and a 12 l NaI(Tl)-detector array for our measurements. Both detectors measured simultaneously. Gamma-ray spectra were recorded every two seconds with the NaI(Tl)-spectrometer and every ten seconds with the HPGe-spectrometer.

Due to the bad weather conditions we could only fly over three measurement areas and the test area. A ^{137}Cs-source and a ^{60}Co-source were positioned within the test area, which enabled to check the calibration of the measurement systems.

In the test area we focused our interest on two aspects:

On the one hand the laboratory calibration of the two detector systems for the radionuclides ^{137}Cs and ^{60}Co should be verified. Therefore the two sources were overflown in a direct flight path (trajectory a). On the other hand the flight regime with flight paths of 100 m distance and a flight altitude between 60 m and 100 m should be practiced (trajectory b). The trajectories of the two flight regimes and the locations of the ^{137}Cs- and ^{60}Co-sources are shown in Figure 1. Each section of trajectory b is numbered.

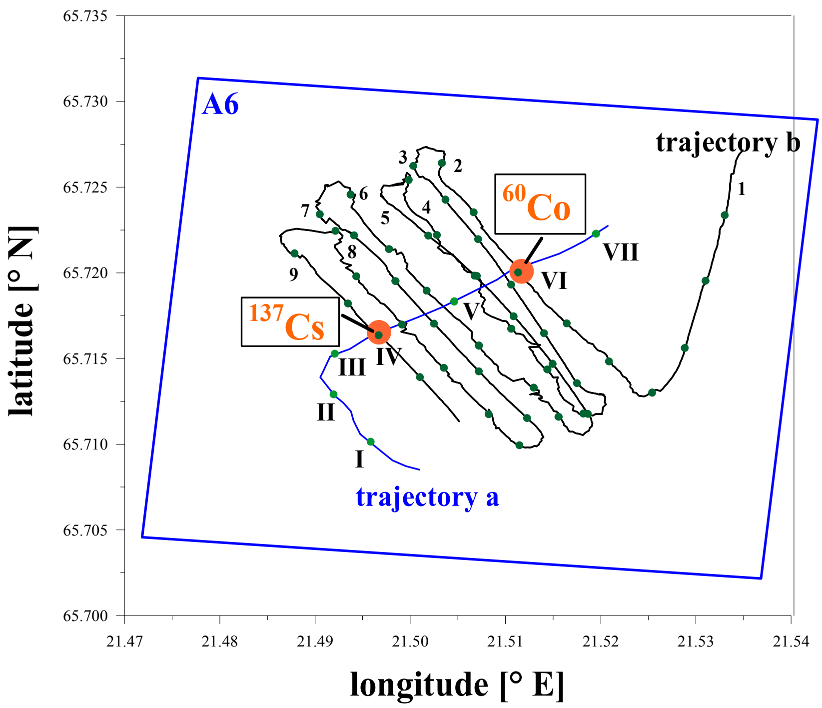


Figure 1: Trajectories of the two flight regimes in area A6 and the locations of the ^{137}Cs- and ^{60}Co-sources.

In Figure 2 the net count rates of the ^{137}Cs window (600 – 720 keV) and ^{60}Co window (1050 –1400 keV) determined with the NaI(Tl)-detector array are plotted. For the calculation of the net count rates in the above mentioned windows we used the stripping coefficients which were determined from measurements of a set of calibration pads doped with potassium, uranium series and thorium series activities. Further the net count rates were normalized to a flight altitude of 100 m.

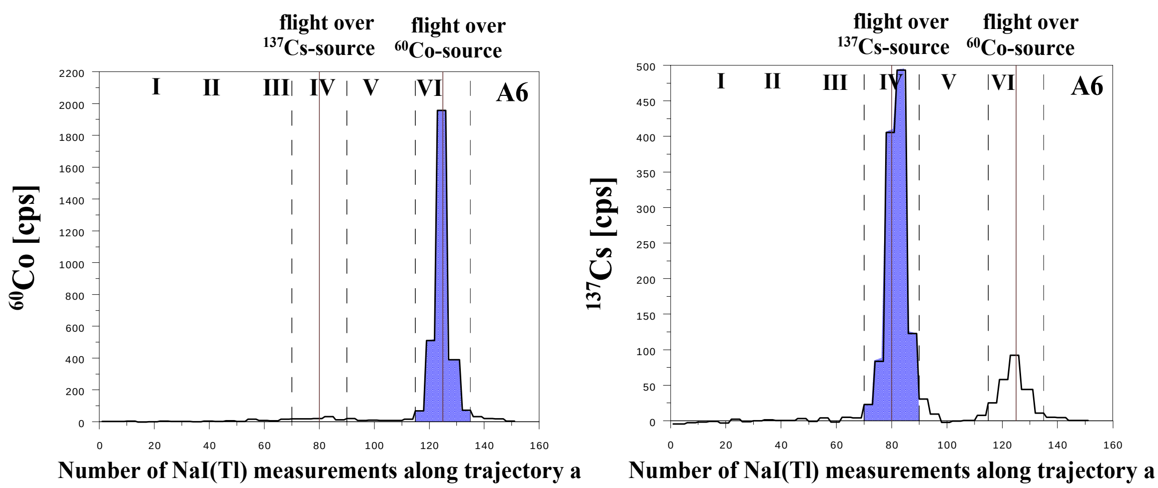


Figure 2: Net count rates of ^{137}Cs and ^{60}Co along trajectory a. The Greek numbers indicate the position along the flight path (Figure 1).

Within the ^{137}Cs window a small peak is identifiable when we overflew the ^{60}Co source. This peak is caused by the incomplete stripping of the ^{60}Co fraction within the ^{137}Cs window. To solve this problem further mathematical operations will be done.

As both sources have not been shielded the activities can be calculated by the equation (1):

$$A = \frac{N \cdot 4 \cdot \pi \cdot h^2}{p_\gamma \cdot \varepsilon_E \cdot t} e^{(\mu_L \cdot h)}$$

with

A: activity of the source [Bq]
N: counts of gamma rays detected per second
h: flying altitude [m]
p_γ: emission probability of the gamma ray energies being considered
ε_E: detector response of the gamma ray energies being considered [m^2]
μ_L: mass attenuation coefficient in air of the gamma ray energies being considered [m^{-1}]
t: time [s]

Using Equation (1) and the maximum count rates shown in Figure 2, the activity of the ^{137}Cs-source is calculated to be 2.7 ± 0.5 GBq and the activity of the ^{60}Co-source to be 5.00 ± 0.3 GBq. These values are in very good agreement with the activities (2.8 GBq (^{137}Cs), 5.0 GBq (^{60}Co)) published by the organizer.

In a second flight above the test area (trajectory b) this field was overflown with parallel flight paths and a distance between them of about 100 m. The ^{60}Co-source was identified on the flight sections 2, 3, 4 and 5 and the ^{137}Cs-source was identified on the flight sections 8 and 9 (Figure 3). The calculated activities of both sources are equal to the values mentioned above.

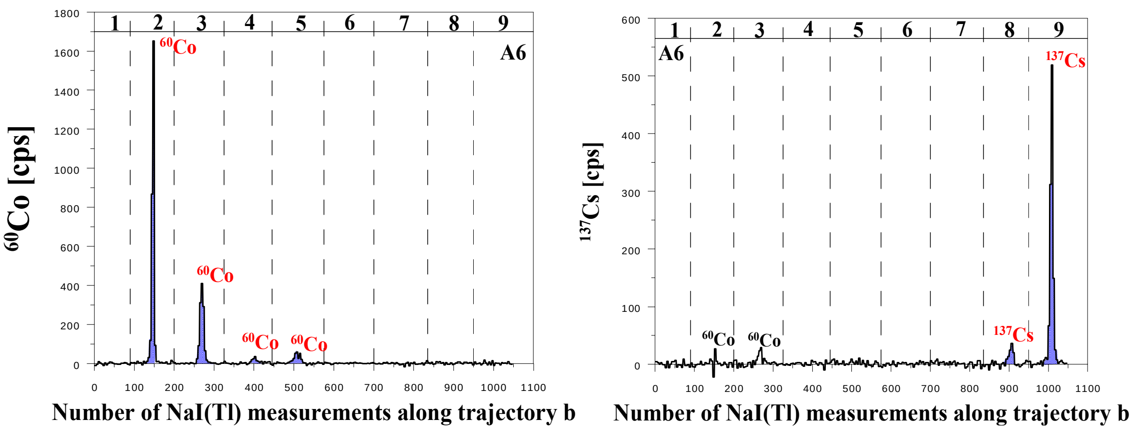


Figure 3: Net count rates of ^{137}Cs and ^{60}Co along trajectory b. The numbers indicate the different flight sections, which are presented in Figure 1.

Additionally to the evaluation of the NaI(Tl) spectra the HPGe spectra gave us the possibility to clearly identify individual radioactive nuclides. In Figure 4 the spectra I, IV and VI recorded by the HPGe-detector along trajectory a are shown. Spectrum 1 shows the background situation without any radioactive sources. In contrast, spectrum IV was measured near to the ^{137}Cs-source and spectrum VI near to the ^{60}Co-source.

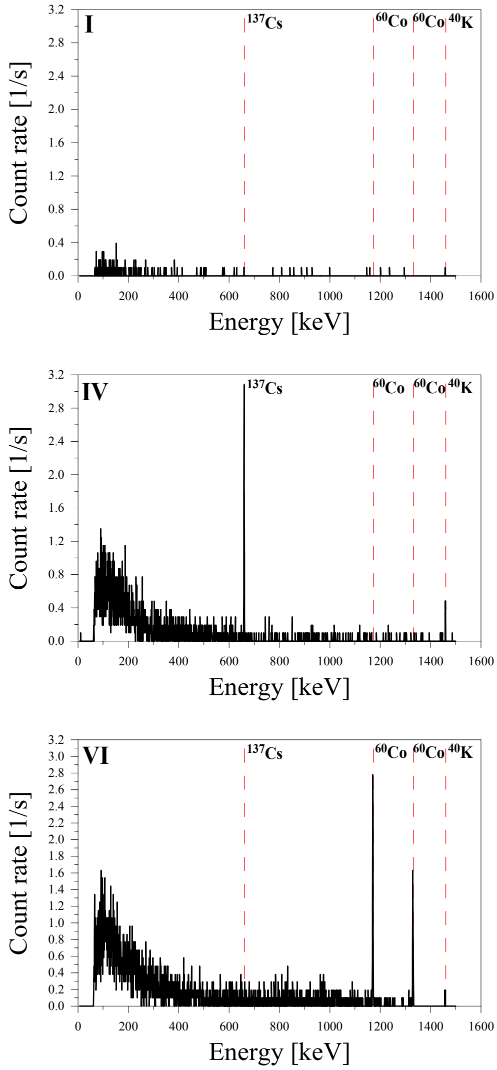


Figure 4: 3 selected HPGe-spectra along the trajectory a.

Based on this perception from the test field, it was clearly shown that the calibration factors are correct and the chosen flight regime was usable for the search of radioactive sources. Nevertheless we tested different flight regimes at other measurement fields to find out the best way to overfly a certain area. Two flight regimes are shown in Figure 5.

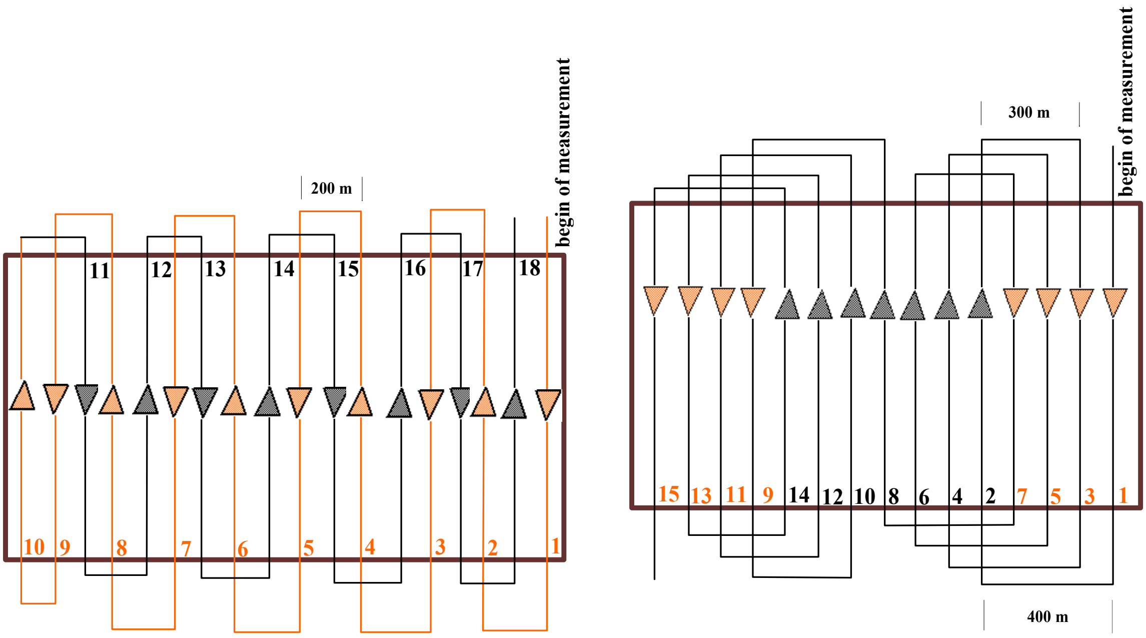


Figure 5: Two flight regimes (trajectories), which guarantee a distance of 100 m between different flight sections.

For the presentation of our results from the measurement areas we show as an example area A4. Two ^{60}Co sources, four ^{137}Cs sources and a ^{192}Ir source were positioned. The locations of the sources and the flight regime are shown in Figure 6.

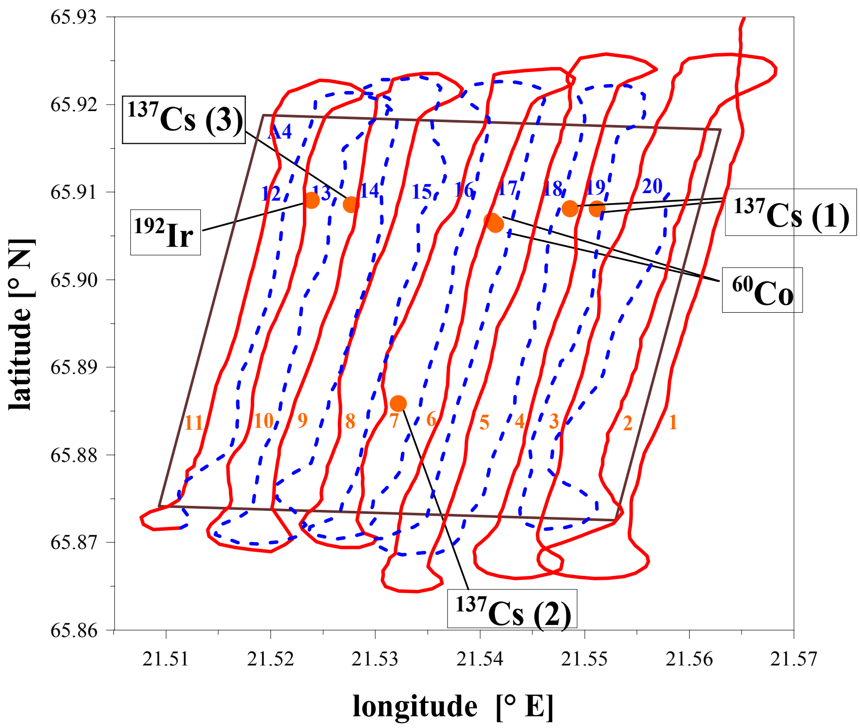


Figure 6: Trajectory of the flight regime in area A4 and the locations of the ^{137}Cs-, ^{60}Co- and ^{192}Ir-sources.

In the data evaluation we first calculated the net count rates within the ^{60}Co window along the trajectory of this flight. As presented in Figure 7 a ^{60}Co-source was overflown during the flight section 6, whereas in the flight sections nearby (16,17) no increased ^{60}Co net count rates were detected.

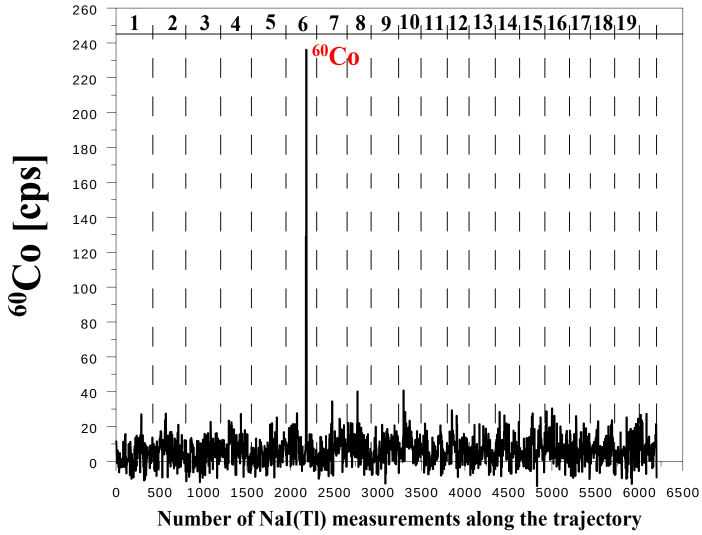


Figure 7: Net count rates of ^{60}Co along the flight path. The numbers indicate the different flight sections, which are presented in Figure 6.

The profile of the ^{137}Cs net count rates along the trajectory is plotted in Figure 8. Here, several regions with increased net count rates could be identified. A detailed data analysis showed that for example the higher net count rates during flight section 6 can occur due to the influence of ^{60}Co as also seen in the test flight area. Increased net count rates in flight sections 10, 11, 12 and 13 which were detected simultaneously in the low energy (250 – 500 keV) spectrum could be related to the radionuclide ^{192}Ir. Thereby the increased count rates in the ^{137}Cs window are caused by Iridium peaks at 604 keV (8.2 %) and 612 keV (5.3 %). The dominant peaks of ^{192}Ir lie at 296 keV (29.6 %), 308 keV (30.7 %), 316 keV (82.7 %) and 468 keV (47 %) and can be detected in the low energy window. As shown in Figures 7, 8 and 9 the ^{137}Cs(1)-sources are measured in flight sections 4 and 19, the ^{137}Cs(2)-source is detected in flight section 7, the ^{60}Co-source is measured in flight section 6 and the ^{192}Ir source is found in flight sections 10, 11, 12 and 13. Only the ^{137}Cs(3)-source could not be located.

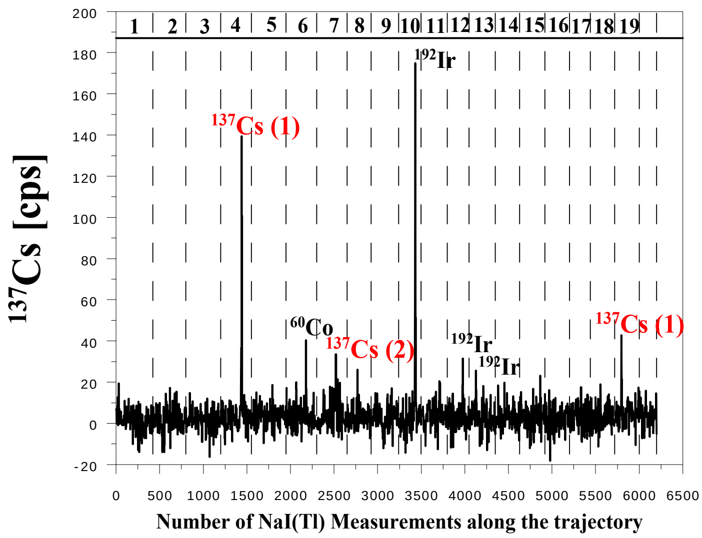


Figure 8: Net count rates of ^{137}Cs along the flight path. The numbers indicate the different flight sections, which are presented in Figure 6.

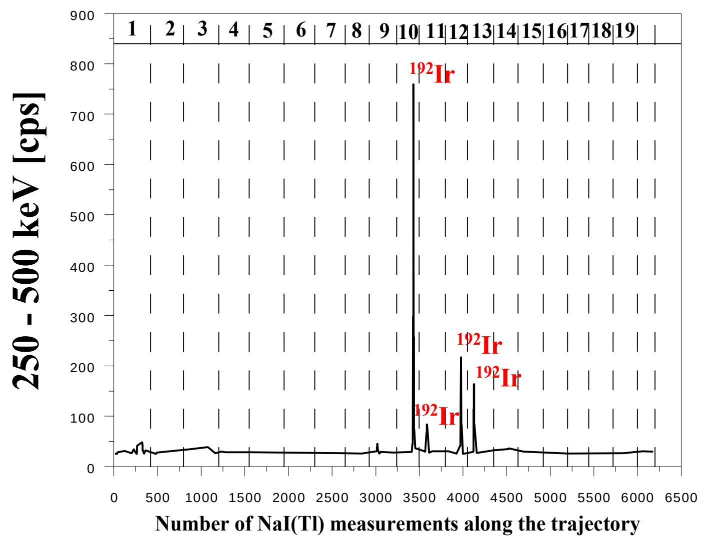
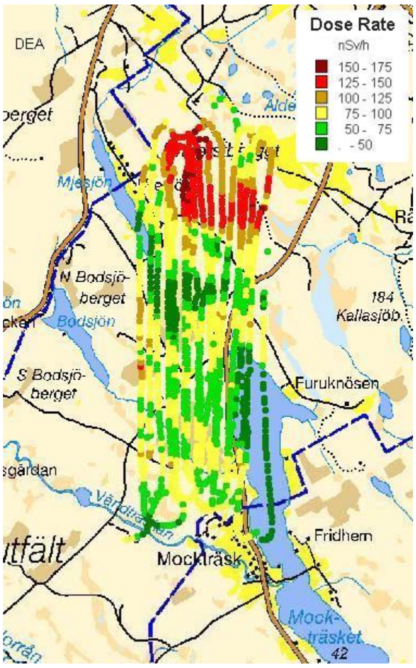


Figure 9: Net count rates of 192Ir along the flight path. The numbers indicate the different flight sections, which are presented in Figure 6.

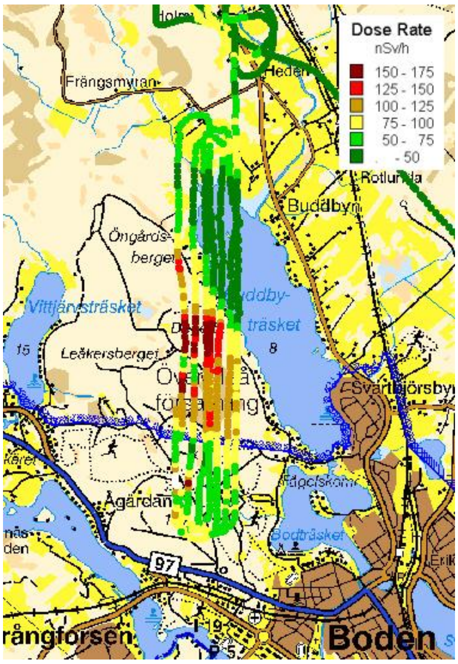
Mapping of natural radionuclides

In addition to the identification and determination of the activities of the radioactive sources within the areas A2, A3 and A4 we calculated the specific activities of the natural radionuclides and the dose rates. The dose rate in nSv/h of the areas A2, A3 and A4 are plotted in Figure 10. As expected the dose rates over sea are clearly lower than over land.

A2



A3



A4

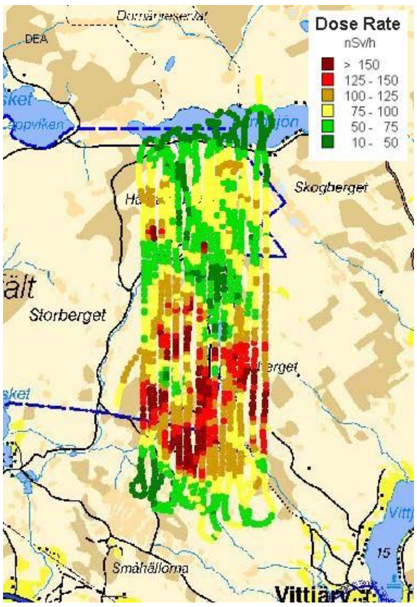


Figure 10: Measured profiles of the dose rates in the areas A2, A3 and A4.

Conclusion

As a result we can conclude that the exercise “Barents Rescue 2001” contributes in an important way to assure the quality of the airborne measurements from the BfS and BGS. Furthermore it documented the effectiveness of the aerogamma spectrometry for the search of hidden radioactive sources. This exercise served to optimize the measurement systems and the data evaluation in future.

Norway, team NOC

Norwegian Team (NOC)

Thor Engøy[*], Maj. Lars Antonsen[†], Maj. Kjetil Vik, Capt. Vebjørn Karlsen, Capt. Håkon Kristensen, Lt. Torbjørn Enger, Lt. Jan Ivar Johansen, 2. Lt. Kai Henning Bjøreng, Raymond Andreassen.

Equipment

- Airborne platform: Sea King MK-43B helicopter belonging to the Royal Norwegian Air Force, primary purpose search and rescue
- Detector assembly: Exploranium GPX 1024 with 4 detectors each consisting of a 4 l NaI (Th) crystal and a photomultiplier tube.
- Data collection hardware: Exploranium GR820 for automatic detector gain control and multichannel analysis (256 channels)
- Navigation data collection: Garmin 12XL handhelp GPS with external antenna and serial interface
- Computer: Dell Latitude Cpt laptop computer with extra serial port
- Data collection software: Geological Survey of Norway (NGU) Mobile Gamma-Radiation Monitoring program
- Data replay software: NGU Mobile Gamma Radiation Measurement Replay program (example of run given in Figure 1)

Methods

Flying height: 60 m; flying speed: 50 knots; line spacing: 200 m.

Sampling time: 1 s.

Detector position: inside plywood box, strapped to the floor inside the helicopter, on the left hand side and approximately in the length wise middle, above filled fuel tanks.

Search method: start in one corner of rectangular search area and perform searches parallel to the longest side separated by 200 m and record manual "hits"; upon completion of area scan, perform a closer positioning / data collection of specific hits.

Data analysis

Source localization: sources were located by moving the helicopter in four directions relative to early position; possible buildings or platforms that could house the sources were noted.

Source identification: sources were identified by visual inspection of spectra, comparing them with spectra of expected industrial sources (Cs-137, Ir-192, Co-60).

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[†] DEFCOMNON, NAE

Source strength estimation was not attempted. Total count data during hover over sources were reported.

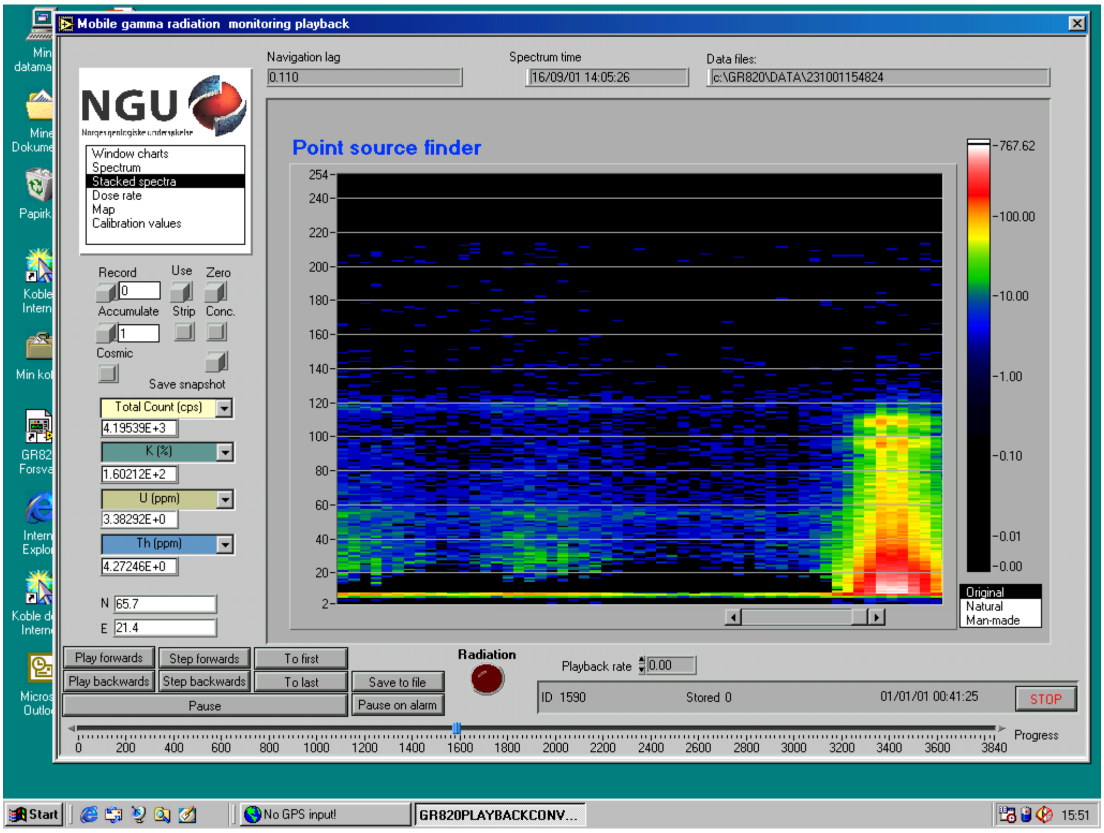


Figure 1: Post search replay of data using software developed by the Geological Survey of Norway. Shown is the “stacked spectra” display where a Co-60 source is identified on the fly.

Results

A1:

Co-60 at NE Stortjärnen, S Stortjärnen and W Risheden found.

I-131 at E Rishedsmyran not found during search. Postprocessing of data not meaningful due to garbled navigational data.

A2:

Not searched

A3:

Co-60 at ENE Ågärden found

A4:

Search incomplete (and without instrument and source identification support personnel)

A5:

Ir-192 at E Svenskberget found; Co-60 and Cs-137 at W Kusträsket found. Location of all sources shifted north. Probable cause of discrepancy: decimal fraction of minutes reported as opposed to minutes and seconds expected by recording group

Co-60 at NNW Kusträsket not found during search.

The following trial was not reported: During one of the above searches a signal was detected in the vicinity of a moving car. It was attempted to check whether the signal came from the car. However, a quick pass along the road could not locate the car and normal search pattern was resumed.

Conclusions

Exercise goals

The Norwegian gamma search teams (NOA, NOB, NOC) had the following goals for the exercise:

- Pilot test instrument with NGU data collection and replay software onboard Royal Norwegian Air Force helicopters
- Train crews with no prior experience in airborne gamma search in operation of the instrumentation; train support personnel
- Collect, interpret (source identify) and report data to Gamma Search Cell, including processed data (doserate) in NKS-format
- Evaluate and compare various helicopter platforms for ease of use of the instrumentation

Only Sea King MK-43B helicopter (NOC) received preliminary acceptance for operating the instrumentation onboard. This impacted the training of other crews directly and the comparison between platforms.

All other goals and expectations exceeded:

- Various fixes were made during the exercise. Instrument stabilization was greatly improved after signal from defective detector was discarded. Subsequently the instrumentation package could be deployed at 10 minutes notice. Blown fuses due to erroneous polarity in ground power supply were changed. Two bug fixes to a PC program performing GPS data conversion were made. During playback of data it became evident that the energy calibration was slightly altered after hover over Co-60 source. To improve K-40 stabilisation, 500 g of Seltin salt was brought onboard during search.
- The helicopter crew became very capable in the course of the exercise in manoeuvring and identifying certain sources directly online.
- Sources were identified from all searched areas. With aid from GSC one NKS-formatted file was mapped during a pre-exercise search. Four files were handed in during the exercise, two of which were garbled.

Possible improvements: gains

- Service poorly functioning detector: increased signal to noise ratio (4 detectors instead of 3)
- Incorporate navigational data collection (in decimal fraction minutes) into gamma monitoring software: fewer things to go wrong
- Calibrate detector for specific platform and detector placement: allow estimate of source strength
- Acquire post processing capability to compare to / search for known sources from library: quicker identification of a wider set of sources
- Acquire post processing capability of results mapping: improved location of sources
- One-button start-up of data collection: less risk of data loss due to operator error

Acronyms

Acknowledgement

We gratefully acknowledge the support of the Geological Survey of Norway in providing their software and installing it on our measurement system. A special thanks goes to Mark Smethurst and John Mogaard for excellent software and hardware assistance during the exercise. Also the friendly and capable technical support for GSC is highly regarded. Especially the mapping of a trial search during the pre-exercise was greatly appreciated.

References

Smethurst, M. A.: *A Mobile gamma ray spectrometer system for nuclear hazard mapping*, NGU Rapport 2000.088

Russia, team RUA

Russian Team (RUA)

Nikolai Drozdov, Emercom

Team members

Helicopter commander – 1

Engineer - dosimetrist - 2

Equipment

Air magnetometer "AeroMaster"

Air gamma-spectrometer "Urtec PEI GPS"

Air gamma-survey set

On-board computer

Pilot indicator

Accumulator

Charging device

Methods

Detection of radionuclides using the spectrometric method. Flight altitude – 70-80 m. Flight speed – 110-120 km/h.

Data analysis

Defined in real time.

Results

7 ionising radiation sources were found.

Conclusions

We could not fully demonstrate our technical facilities

Limited number of flights

Unfavourable weather conditions

Bad radio communication with personnel at collection and analysis of data location

Problems using the reporting forms issued by REAC

Sweden, team SEA

Swedish Team (SEA)

Sören Byström
Peter Hagthorpe
Anders H. Lindén
Ari Tryggvason
Mats Wedmark
Ulf Adolfsson (Aircraft Company)
Hardy Häggman (Aircraft Company)

Equipment

Fixed Wing Aircraft. Shrike Commander 500S.

Equipment used is part of standard equipment for airborne geophysical measurement.

Exploranium GR820 with 16.8 litres downward and 4.2 upward looking NaI detector.

256 channels data 12.5 keV.

Sampling time 1 second.

Positioning system DGPS. Altitude above ground measured with radar Altimeter.

Methods

Nominal altitude above ground 60 meter.

Aircraft speed 250 km/h (70 m/s)

Line spacing 100 meter.

Detector is mounted in luggage room in aircraft. Upward looking detector is somewhat shielded of fueltank.

No source recognition on line in aircraft.

Search method: Straight lines over the area on different heights. Due to time limits (50 minutes) only one altitude used.

Data analysis

Two different methods used.

Method 1

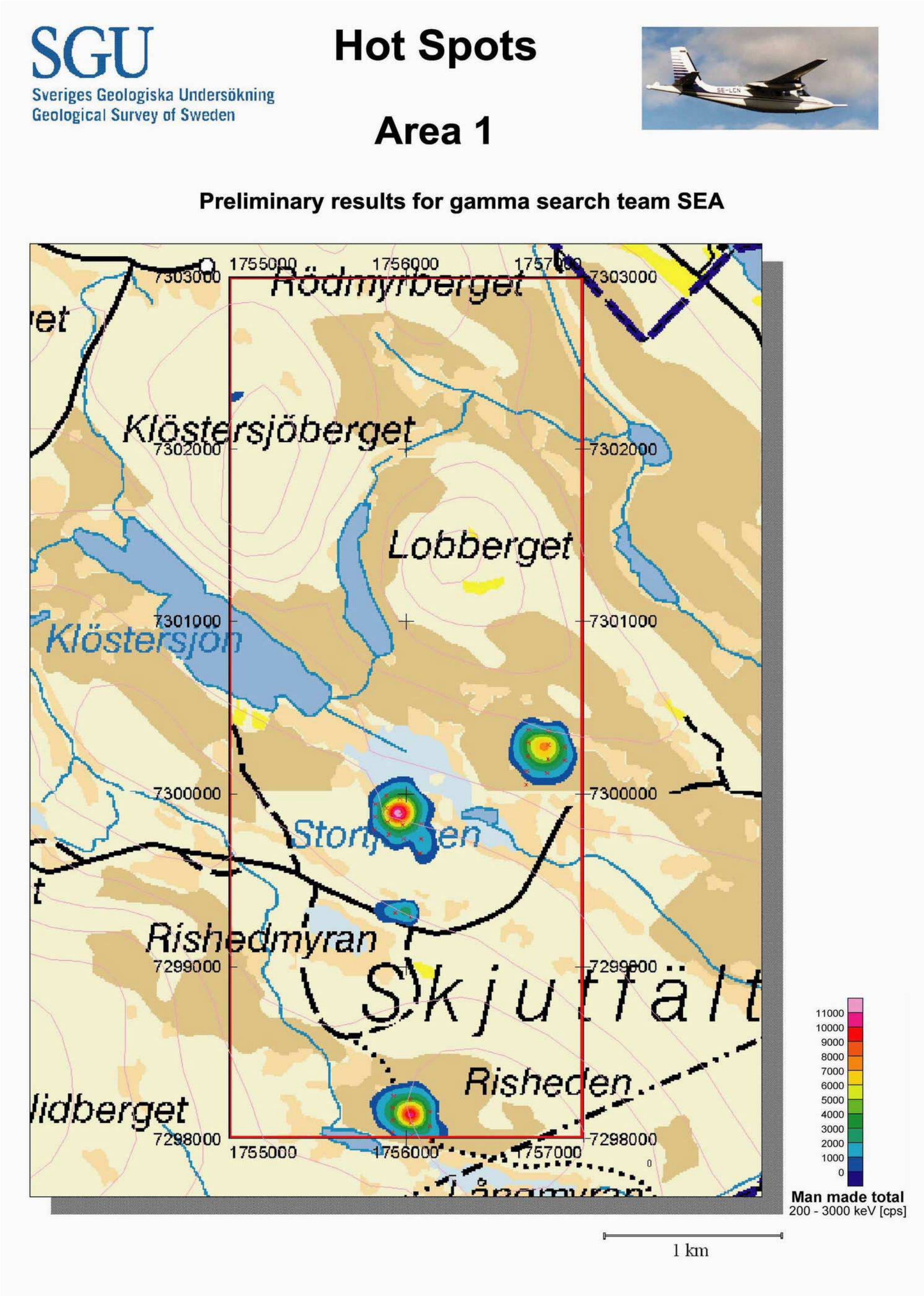
- Selectable ratios between low part (<1.4 MeV) and high part (>1.4 MeV) of spectra.
- Thorium, Uranium and Potassium are reduced from channel data, with the assumption that there is no manmade influence above 1.4 MeV. Selectable windows to show parts of remaining data.
- Natural Dosrate and manmade Dosrate automatically calculated.
- Alert levels that warn if any ratio, Manmade window, Dosrate etc is outside given limits.
- Nuclide strength. A rough figure form manmade dosrate in microGy/h.

Method 2

Based on SVD, Potassium, Uranium and Thorium are reduced from data, or rather all data that are not point sources are reduced.

Selectable windows to show parts of remaining data.

Results

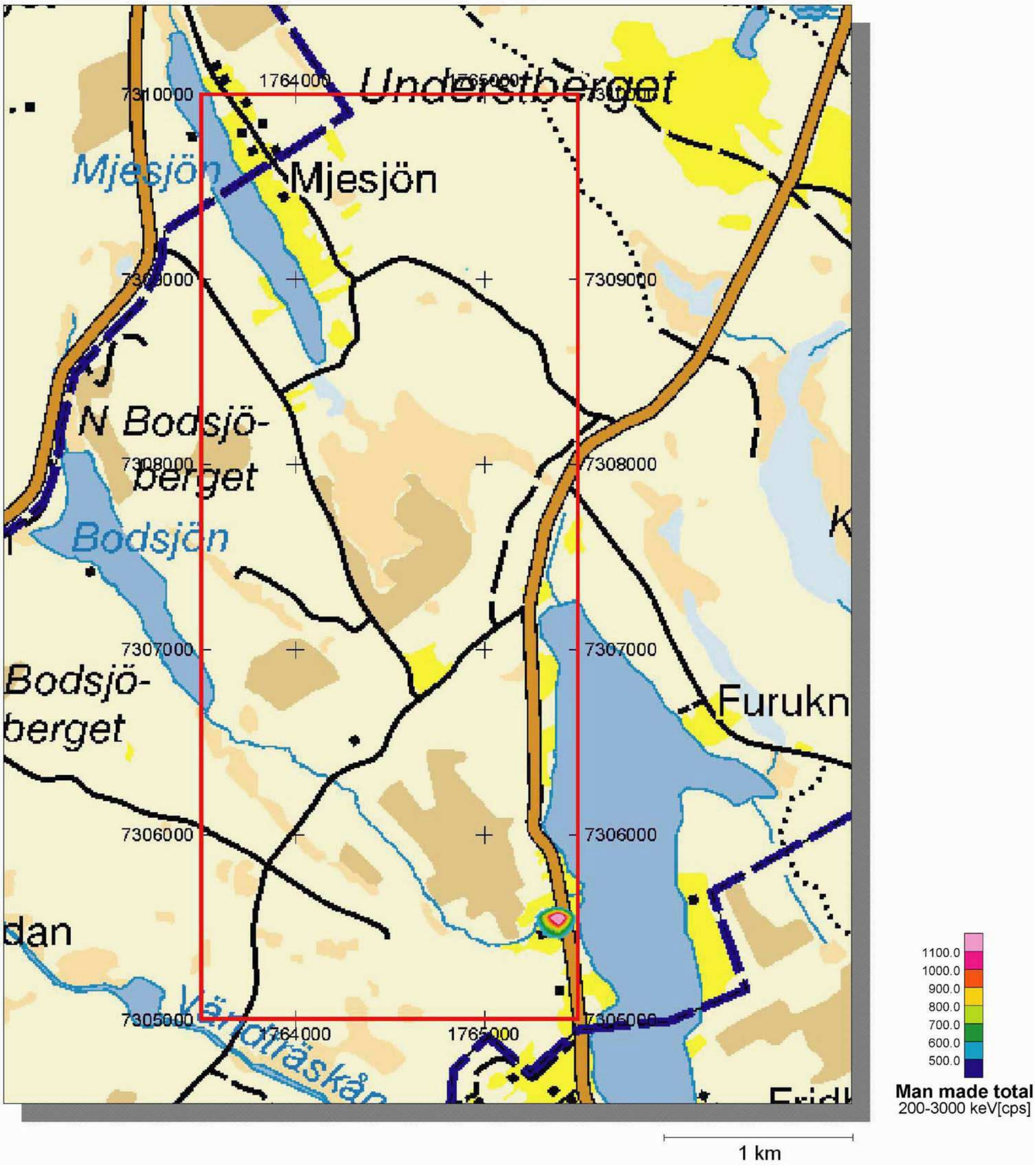


SGU
Sveriges Geologiska Undersökning
Geological Survey of Sweden

Hot Spots

Area 2

Preliminary results for gamma search team SEA

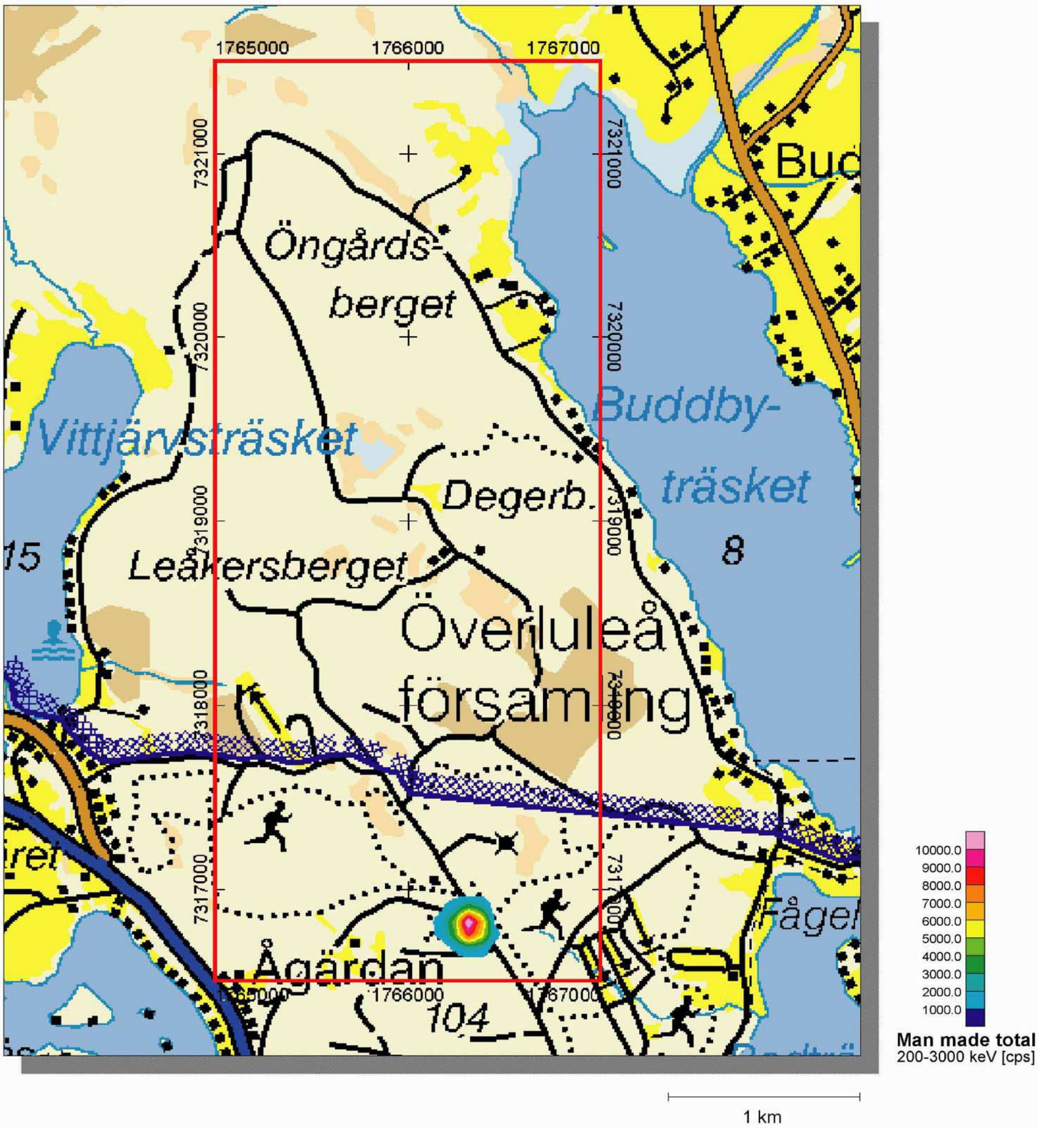


SGU
Sveriges Geologiska Undersökning
Geological Survey of Sweden

Hot Spots

Area 3

Preliminary results for gamma search team SEA



The results for Swedish team SEA

Area 1. Sources reported after one hour after landing was correct. All sources were found and correct nuclide was reported.

Area 2. Co-ordinates for sources reported after one hour after landing was correct. One source was found. Wrong nuclide was reported (Cs-134 instead of MO-99)

Area 3. Sources reported after one hour after landing was correct. All sources were found and correct nuclide reported.

The work carried out the following days indicated a few more sources (in the region of acceptable signal to noise ratio).

Conclusions

Line spacing 100 meters and an altitude of 60 meters was used.

In a real situation, Fixed wing aircraft probably has been used for a wider search and Helicopters/Cars for more detailed search. If so an altitude between 100 to 150 meter and a line spacing of perhaps 200 meters in a first search have been a reasonable compromise.

As the difficult task is to select correct hotspots form data where signal to noise ratio is low, future efforts will be focused on that.

Sweden, team SEB

The Swedish AGS team (SEB)

Simon Karlsson, Hans Mellander

Swedish Radiation Protection Authority

Equipment

At SSI there is no system dedicated for airborne measurements at present and therefore the exercise was an excellent opportunity to develop and test a system for airborne gamma spectrometry and also to test the co-operation with the Swedish armed forces. The installation was made together with the Swedish Defence Research Agency (team SEC) and the Swedish Defence Material Administration, FMV. Two Swedish “helicopter 9” or MBB BO 105 was used for the installations.

Figure 1. The helicopter used by team SEB was of the type MBB BO 105.

The helicopter was equipped with systems available at our laboratory. The detectors are normally used for ground-based measurements so they are not optimised for AGS measurements. The two systems consisted of the following:

A HPGE-system containing:

- 70 % HPGe detector from EG&G Ortec
- Dart Multichannel analyser from EG&G Ortec
- SveeEight GPS from Trimble
- Latitude C800 from Dell

A NaI-system containing:

- 5”x 5” NaI detector (1,6 litres)
- GDM 40 RPS from Gammadata
- Latitude C800 from Dell

The intension was to use the NaI system to find and quantify the sources while the HPGe system mainly was aimed for identification purposes. They were placed in the rear end of the helicopter to get the best possible field of view while measuring. The problem with the helicopter type used is that the fuel tanks are situated underneath the floor resulting in a high and variable attenuation of the incoming photons. Even though it would have been preferred we didn't have the time or possibility to mount the detectors externally.

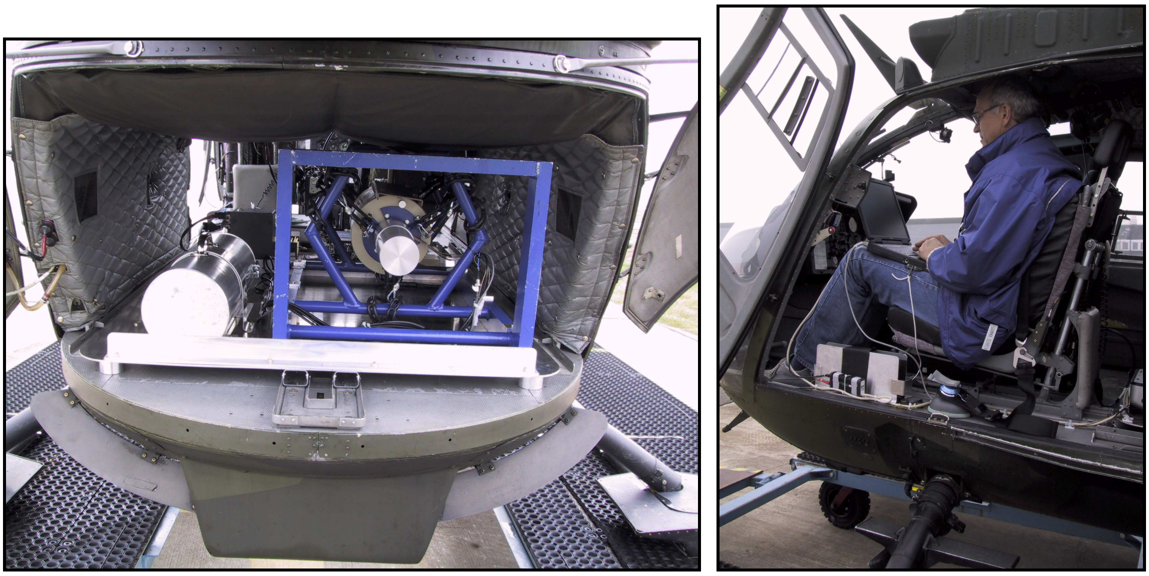


Figure 2. The two detectors were placed in the rear end of the helicopter. The measurements were controlled by two operators with laptops.

All equipment was installed on two aluminium plates, one for the detectors and one for the electronics. Power was taken from the helicopter and no internal batteries were used in the systems. The two GPS receivers were fed with a signal from an antenna placed in the front window of the helicopter.

Methods

The methods used for the measurements were developed during discussions before the exercise and during the pre-exercise test flights. The fact that an area of 2 x 5 km was to be measured within 50 minutes gave rise to the question whether covering the whole area was more important than to follow up indications of sources in more detail. It was decided that the whole area should be covered since the car teams were supposed to follow up the indications.

The pre-exercise test flights were to a large extent dedicated to co-operation with the pilots, navigation and testing the speed needed to cover the area within the time limit. It was finally decided to fly at a speed of around 80 knots and to use 100 meter line spacing. To avoid too sharp turns the whole area was flown with two hundred meter line spacing at first and then this was repeated a second time with one hundred meters displacement of the flight lines. By the use of this method the whole area could at least be sparsely covered even if time- consuming problems arose during the measurement. A few times there was a couple of minutes left for further investigation after covering the whole area. That time was used to check places where a source was suspected or to check whether places where a large response had been obtained concealed more than one nuclide. The HPGe-detector proved useful in these situations. During all measurements the flight height was held to the minimum limit of sixty meters (200 feet) from the radar altitude meter in the helicopter. The integration time used was two seconds for both systems.

Data analysis

Since it wasn't known what nuclides the hidden sources consisted of it was first discussed to use a peak search method on the collected spectra to be able to find sources of any energy. With good statistics this could have been a useful method, at least for the HPGe-system. Since the expected count rate was too low it was instead decided to use windows to cover suspected nuclides while the total count rate and some quotients between low and high energy were used for nuclides not accounted for. In co-operation with Thomas Hjerpe from the University of Lund we also implemented a "moving background" method where the average window count rate for the latest x spectra was compared with the y spectra before them.

The software normally used at SSI for mapping of extended sources like fallout or natural radiation were not optimised for the search of point sources. A lot of effort was put into modification of existing software and construction of new software during the months before the exercise. The Swedish measurement teams from SSI and FOI were also reinforced by Benno Bucher from Switzerland. The software developed by him and Hans Mellander was used with the HPGe-system during the flights. The different software included digital maps with preset flight lines, navigation support, time plots of all calculated parameters and rainbow spectra. Alarm levels could be set to each of the parameters. The NaI-system used a peak search method applied to the calculated parameters and a scrollbar could be used to continuously optimise the colour scale in the plots of all parameters. These two functions proved to be very efficient.

With the time limit of 1 hour for delivery of the SIR-documents there was no time for detailed analyses of the data. During the flight we took notes of places where sources were found or suspected. After landing the data from both systems was compared by checking one flight line at a time for suspected sources. The SIR-documents together with NKS-files with total counts were delivered within one hour (almost) to REAC. A few times the delivered data was updated after a more detailed analysis. The locations of the sources were also delivered to the two Swedish car teams SEK and SEL for follow up of our indications the next day.

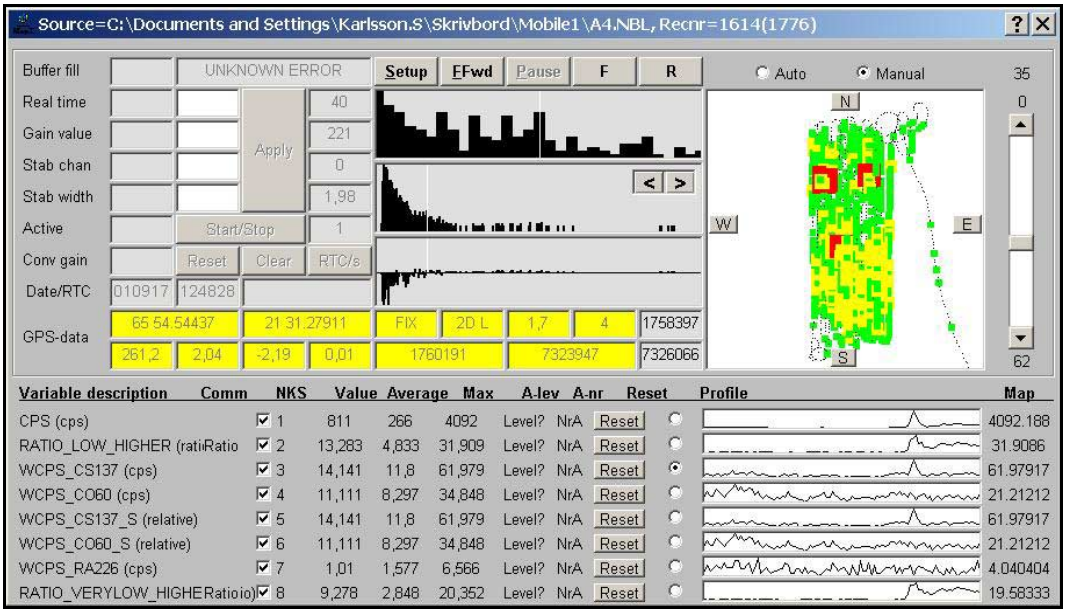


Figure 3. The analysis and visualisation software used for the NaI-system showing a measurement in area A4.

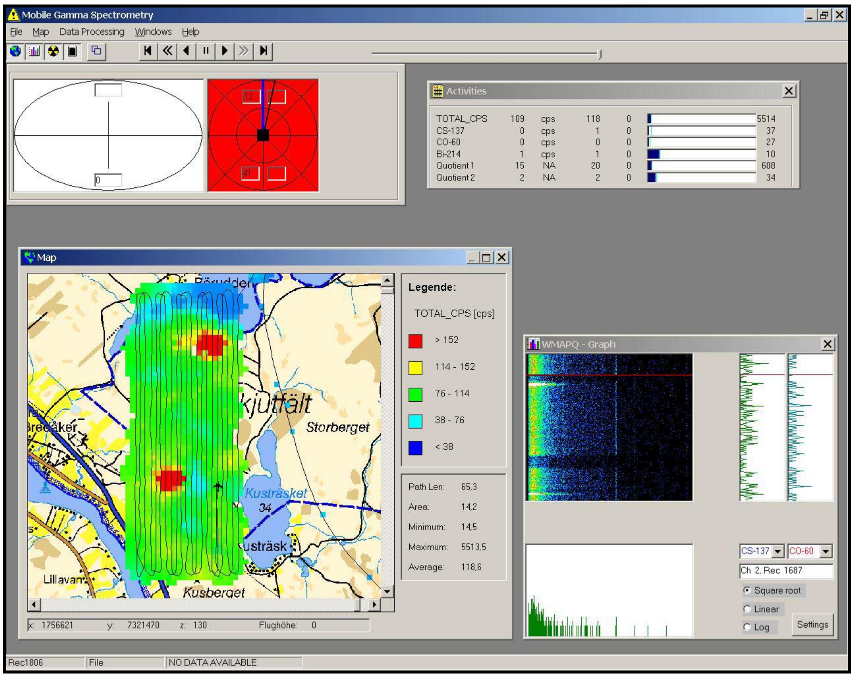


Figure 4. The visualisation software used for the HPGe-system showing a measurement made in area A5.

Results

The tables below show the reported sources from team SEB together with the true sources and their locations. In most cases we did not try to estimate source activity but sometimes CPS was reported as an indication to the strength of the source.

Table 1. Area A1 – All sources were found and one more was reported as suspected.

Reported source	Reported location	Comment	True source / Source code	True location	Activity (GBq)
Co-60	1755973 7298118	Source clearly seen with both systems.	Co-60 / 1:1	1756005 7298134	5
I-131	1755976 7299189	Source clearly seen with both systems.	I-131 / 1:2	1756005 7299224	9.25
Co-60	1756001 7299850	Source clearly seen with both systems.	Co-60 / 1:3	1755956 7299830	5
Co-60	1755890 7299810	The same source was by mistake reported for two adjacent flight lines	-	-	-
Co-60	1756700 7300300	Source clearly seen with both systems.	Co-60 / 1:4	1756747 7300334	5
Cs-137	1755316 7299429	Possible source seen with NaI but nothing seen with HPGe.	No source	-	-

Comment: After area 1 was covered with flight lines we had a few spare minutes to hover over source 1:1 and 1:3 to check for other nuclides than Co-60. No additional sources were found.

Table 2. Area A2 – No sources were found in this area. We started to get worried here!

Reported source	Reported location	Comment	True source / Source code	True location	Activity (GBq)
-	-	No source found.	Co-60 / 2:1	1764029 7307246	5
-	-	No source found.	Co-60 / 2:2	1764048 7307266	5
-	-	No source found.	Mo-99 / 2:3	1764844 7307031	3.1
-	-	No source found.	Mo-99 / 2:4	1765350 7305451	18
-	-	No source found.	Cs-137 / 2:5-1	1763466 7306095	3 x 0.5
-	-	No source found.	Co-60 / 2:5-2	1763466 7306095	3 x 0.02

Table 3. Area A3 – The Co-60 source was easily found.

Reported source	Reported location	Comment	True source / Source code	True location	Activity (GBq)
Co-60	1766244 7316818	Large response on both HPGe and the NaI system.	Co-60 3:1	1766304 7316848	4 x 5

Comment: At first we reported two additional sources in area A3 but those reports were cancelled after further analyses in the same evening.

Table 4. Area A4 – Three (or five) out of seven sources was found.

Reported source	Reported location	Comment	True source / Source code	True location	Activity (GBq)
-	-	No source found.	Cs-137 4:1	1760923 7321390	0.4
-	-	No source found.	Cs-137 4:2	1760488 7323895	2.5
Ir-192	1760303 7323910	10 times background (cps).	Ir-192 4:3	1760310 7323933	13
-	-	Possibly seen together with the Co-60 source below.	Co-60 4:4	1761137 7323702	5
Co-60	1761120 7323767	6 times background (cps).	Co-60 4:5	1761117 7323744	5
Cs-137	1761492 7324048	3 times background (cps).	Cs-137 4:6	1761442 7323932	1.3
-	-	Possibly seen together with the Cs-137 source above.	Cs-137 4:7	1761559 7323941	1.9

Comment: An additional Cs-137 source was reported at first but it was cancelled after further analyses. A few spare minutes after covering the area was used for hovering over the Ir-192 source. We suspected a Cs-137 source there but it couldn't be found.

Table 5. Area A5 – All sources were found even though source 5:1 was reported as Cs-137 instead of Co-60.

Reported source	Reported location	Comment	True source / Source code	True location	Activity (GBq)
Cs-137	1756884 7322015	Reported as a suspected, very weak source.	Co-60 / 5:1	1756869 7322034	40
Cs-137	1755704 7321628	Reported in the same place as the Co-60 source below.	Cs-137 / 5:2	1755733 7321627	2.6
Co-60	1755704 7321628	10 times background (cps).	Co-60 / 5:3	1755750 7321686	2 x 5
Cs-137	1755892 7322989	Suspected source, small response	Cs-137 / 5:4	Moving	1.9
Cs-137	1755977 7322600	Weak source but clearly seen.	Cs-137 / 5:4	Moving	1.9
Ir-192	1756447 7324289	Seen on several flight lines. 40 times background (cps).	Ir-192 / 5:5	1756402 7324293	46

Comment: The vehicle with the moving Cs-137 source was seen during the flight and it was suspected to conceal a source of some kind. Instead of following the car we continued on the flight lines as before.

Conclusions

Taking into consideration the small and internally mounted NaI-detector the results are satisfactory. Since the sources were shielded in many different directions a more detailed evaluation of the system sensitivities is difficult to make but a larger NaI-detector is probably necessary to find sources of lower activity than ~1 GBq and the same accounts for quantification of extended sources. The HPGe detector worked good as a complement to the NaI but could also have been externally mounted for better response to low energy sources.

From an operational point of view everything worked very well except for some small problems with the GPS and some problems with vibrations that mostly occurred while turning the helicopter. The pilots were very professional and the co-operation with them and the other helicopter staff worked very well. The support from the Swedish Defence Material Administration during the exercise days was great.

The exercise delivered a unique possibility to test the capability of the participating teams in finding lost sources. It was very interesting to take part in the measurements and team SEB had the opportunity to fly in all five areas. Because of the very tight schedule and the misty mornings this wasn't possible for all teams. With the large efforts to collect all sources, position them in the terrain and handle them it was a pity that all teams couldn't fly in all areas and also that there wasn't more time for investigation in each area.

All the work needed to keep the systems working, perform the measurements and analyse the data made it almost impossible to visit and follow other parts of the exercise or to socialise with other teams to any larger extent. This was made even worse by the fact that the teams were competing against each other. Competition is fun but it could also have been very interesting to train co-operation with teams from other countries.

Acronyms

SSI – Swedish Radiation Protection Authority

FOI – Swedish Defence Research Agency

FMV - Swedish Defence Material Administration

Sweden, team SEC

Swedish AGS Team (SEC)

Kenneth Lidström and Göran Ågren

FOI NBC Defence

Equipment

The measuring unit was based on two separate systems, one being a 4-L NaI-detector and the other a 50% (relative a 3”x3” NaI) HPGe detector. The NaI system contained a GDM 40 (Gammadata Burklint AB) portable unit, which included MCA, amplifier, high voltage supply, data logger and GPS. For visualization and data storage, a 1 GHz notebook was connected and the software was RPS (made by SSI).

The HPGe system was equipped with a DART (Ortec) unit, which contained MCA, amplifier and high voltage supply. This system was also equipped with the same type of computer as the previous system. For the positioning data a separate GPS unit was connected to the serial port of this computer. The software for this system was also developed by SSI and named DART. The two systems were completely independent except for the GPS antenna.

Figure 1. The picture is taken from the rear side of the helicopter. The red box on the left is the 4-L NaI detector and to the right is the 50% HPGe detector.

All necessary equipment except the computers were mounted on aluminum plates which were placed on the rear floor inside the military helicopter model 9. Three seats were remained, one for the pilot and the other two for the operators of the systems. The detectors were both facing backwards to decrease the shielding effects of the fuel tanks which are mounted under the floor of the helicopter.

Figure 2. The helicopter (hkp-9) that team SEC used during the Barents Rescue exercise. missions.

Methods

According to the exercise regulations, the time limit in each of the 2x5 km areas was 50 minutes. The team chose to use a flight pattern of 20 x 5 km with 100 meter between the flight lines. We used the minimum flight height of 60 meter.

The conditions above gave a calculated minimum velocity of 150 km/h to cover the whole area. The velocity during the missions was approximately 80 knots (~150 km/h) in air speed, which sometimes needed to be corrected for the influence of wind speed. The sampling time for each spectrum was set to 2 seconds. For activity calculations the systems were calibrated against reference sources provided at the beginning of the exercise.

The strategy behind the configuration of the measurement unit was to use the NaI-system for reconnaissance purposes and when a source was detected to use the HPGe-system. The latter was meant do be done with the helicopter hovering over the source to perform a longer sampling time for a more specified nuclide measurement. Due to the time constraint, this strategy was only applied two times. The results were mainly achieved with the NaI-system.

Data analysis

Several energy-windows were set in the systems to cover key-lines (one of the largest photo peaks) from I-131, Ir-192, Cs-137, Co-60 and the natural K-40, Th-232 and U-238 chains. Some of these were also presented in relationships with others (i.e man-made as ratios of natural). These results were presented live on screen and also logged into separate files in combination with position data. For the NaI system with the limited resolution, pulses from a nuclide can appear in other energy windows. This interference was not considered.

Results

The results are described as a comparison to the data given by the exercise staff of real location and activity of the placed sources. These are given for each area as tables (see below). The column named *source activity* describes the declared activity of the source and *reported* activity the activity measured by the team. The column with the header *difference* describes the distance in meter between the location estimated of the team and the given location given by the exercise staff.

Table 1. Reported results from area A1. Three sources were reported from team SEC according to SIR-documents.

NUCLIDE	SOURCE ACTIVITY [GBq]	CODE	REPORTED ACTIVITY [GBq]	DIFFERENCE [m]	PLACED	COMMENTS
Co-60	5	1:01	0.5	87	In wooden cage in gravel pit, shielded upwards with concrete blocks	
I-131	9.25	1:02	Not detected		In shed, collimated with lead bricks upwards and to the W	No trace of I-131
Co-60	5	1:03	0.5	54	In wooden cage at the end of the road	
Co-60	5	1:04	1.0	62	In wooden cage on the south side of the closed road	

Table 2. Reported results from area A2. Two sources were reported from team SEC according to SIR-documents. One of these was later cancelled.

NUCLIDE	SOURCE ACTIVITY [GBq]	CODE	REPORTED ACTIVITY [GBq]	DIFFERENCE [m]	PLACED	COMMENTS
Co-60	5	2:01	0.1	402	Inside the round concrete bunker	False
Co-60	5	2:02	0.1	377	Inside the concrete bunker, collimated obliquely upwards	False
Mo-99	3.1	2:03	Not detected		Inside tracked vehicle cart	
Mo-99	18	2:04	Not detected		In the house on the attic	
Cs-137	3x0.5	2:5-1	Not detected		Inside tracked vehicle cart, level guards, directed upwards	
Co-60	3x0.02	2:5-2	Not detected		Inside tracked vehicle cart, level guards, directed SW	
Am-241	0.0004	2:06	Not detected		In cart, on the inside the hood, about 1.5 m above ground	

Table 3. Reported results from area A3. One source was reported from team SEC according to SIR-documents.

NUCLIDE	SOURCE ACTIVITY [GBq]	CODE	REPORTED ACTIVITY [GBq]	DIFFERENCE [m]	PLACED
Co-60	20	3:01	1.0	24	In storehouse 36, side shielded with lots of concrete blocks

Table 4. Reported results from area A4. Four sources were reported from team SEC according to SIR-documents.

NUCLIDE	SOURCE ACTIVITY [GBq]	CODE	REPORTED ACTIVITY [GBq]	DIFFERENCE [m]	PLACED	COMMENTS
Cs-137	0.4	4:01	Not detected		In red shed, in lead container, side shielded	
Cs-137	2.5	4:02	3.4/1.5	215/ 307	In "birdhouse". Shielded with a lead brick upwards	Two reported locations. Long dist. Interference from Ir-192 rise activity estimation
Ir-192	13	4:03	8.0	97	Radiographic source in a tree	
Co-60	5	4:04	0.5	61	In concrete fire trench, covered with steel plate and sand	
Co-60	5	4:05	0.5	18	In concrete fire trench, covered with steel plate and sand	
Cs-137	1.3	4:06	2.7	89	In tracked vehicle cart, shielded upwards with concrete blocks	
Cs-137	1.9	4:07	2.7	83	In tracked vehicle cart, side shielded with transport contain.	

Table 5. Reported results from area A5. Three sources were reported from team SEC according to SIR-documents.

NUCLIDE	SOURCE ACTIVITY [GBq]	CODE	REPORTED ACTIVITY [GBq]	DIFFERENCE [m]	PLACED
Co-60	40	5:01	Not detected		Radiographic source in drainage drum under the road
Cs-137	2,6	5:02	6.7	33	In red shed, no shielding
Co-60	2x5	5:03	5.3	54	In wooden cage, no shielding
Cs-137	1.9	5:04	Not detected		In car cart moving along the roads, shielded to all sides
Ir-192	46	5:05	10.0	64	Radiographic source below boulder

Conclusion

This was our first experience to practice reconnaissance from helicopter. The first challenge was to install the equipment in the helicopter and receive a flight permission for the complete unit. The physical environment in a helicopter is not ideal in aspects of space, vibrations and attenuating material. In this set-up the main problem was the fuel tank in the floor below the disposable area.

The second challenge was to find a possible way to evaluate spectra with short sampling times (i.e. few pulses per channel) in real time.

The third challenge was to survive in the limited space of the helicopter with the mind focused on a computer screen during sharp turns and sometimes also bumpy flights without vomiting.

As a conclusion, the accomplished results from this exercise exceeded what we hade expected previous to the exercise. The increase in the peak resolution (FWHM) for the HPGe system was about 1.5 keV for 660 keV which can be accepted for these purposes but some work will be made to decrease the influence of the measurement platform. Another aspects is to construct a module that contains these systems and which easily can be installed on many different platforms (primarily in different car- or helicopter models). More work should also be made to develop methods for fast and reliable evaluations of the measurement data in real time.

The lack of distinct peaks during the mission in area A2 created some suspected sources that we in the end generally classified as false. The suspicions were a consequence of the exercise arrangement, since the operators expected to find sources. These expectations probably decreased the threshold for the signal level that could be accepted as significant. In the real situation, it would be possible to reduce such false positives by longer measurement times over suspicious locations. The problem can also be reduced by using more sophisticated methods for data analysis in real time.

The covered distance per spectra, with the speed of 150 km/h, was approximately 80 meter and the distance between each flight line was 100 meter. This gave an uncertainty of at least ± 50 meter for the estimated location of each source. The reported location was also sometimes rounded off.

In area A4, around source 4:02, two sources were reported. An explanation for this can probably be uncertainties in the positioning procedure. The activity estimation in at least one of these was also to high, probably influenced of the higher energy peaks from Ir-192.

The conclusion of the results are that with this type of:

- reconnaissance pattern
- equipment configuration
- flight height
- velocity
- configuration of the detected sources

It is possible to locate a lost source within a radius of 100 meter or less.

Overall: this exercise has been very helpful for further development of these techniques.

Acronyms

AGS Airborne gamma spectrometry

FOI Swedish Defence Research Agency

FWHM Full Width Half Maximum

HPGe High purity germanium

NaI Sodium Iodide

SIR Source Identification Report

SSI Swedish Radiation Protection Institute

Session 3

Team reports, Car Gamma Search (CGS)

Austria, team ATK/ATL

Austrian Team (ATK/ATL)

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Alois Geyrhofer, Gendarmerie Headquarter of Lower Austria
Gerd Schlager, Police Department of Salzburg
Christian Ebner, Police Department of Salzburg
Wohlgang Klösch, Austrian Research Centers Seiberdorf (ARCS)

Equipment

Portable Air - Car Borne System

Detection system:

- Radiation measuring device SSM1. Time of integration: 5 seconds
- External plastic-scintillator-probe or high-volume Geiger-Müller-probes (Gamma-counter)

Data acquisition and navigation system:

- Rugged military laptop
- Built-in modem and GPS with external antenna
- Mobile power pack

With the built-in modem we can transmit measuring and positioning data to headquarters.

Advantages of the System:

- Short installation time (10 min)
- Simplified handling and data analysis (no experts are necessary)
- Usable for car and helicopter operation
- Online navigation with digital map
- Unlimited operation time (depends on power pack)
- Very rugged system (100% ready for duty) (10 systems are on duty in Austria)

Methods

Car-borne gamma search:

- Driving speed: about 30 km/h
- Detector position: inside the car as high as possible
- Measurement: in cps
- Two officers
- Task for the car-borne team is also to mark and secure the dangerous zone (in Austrian: 10 μSv/h)

One officer takes the seat beneath the driver and holds the laptop on his knees. During the measurement the pilot can have a look on the screen, where

- the actually position,
- the track,
- the compass-card and
- the count-rate curve

can be seen.

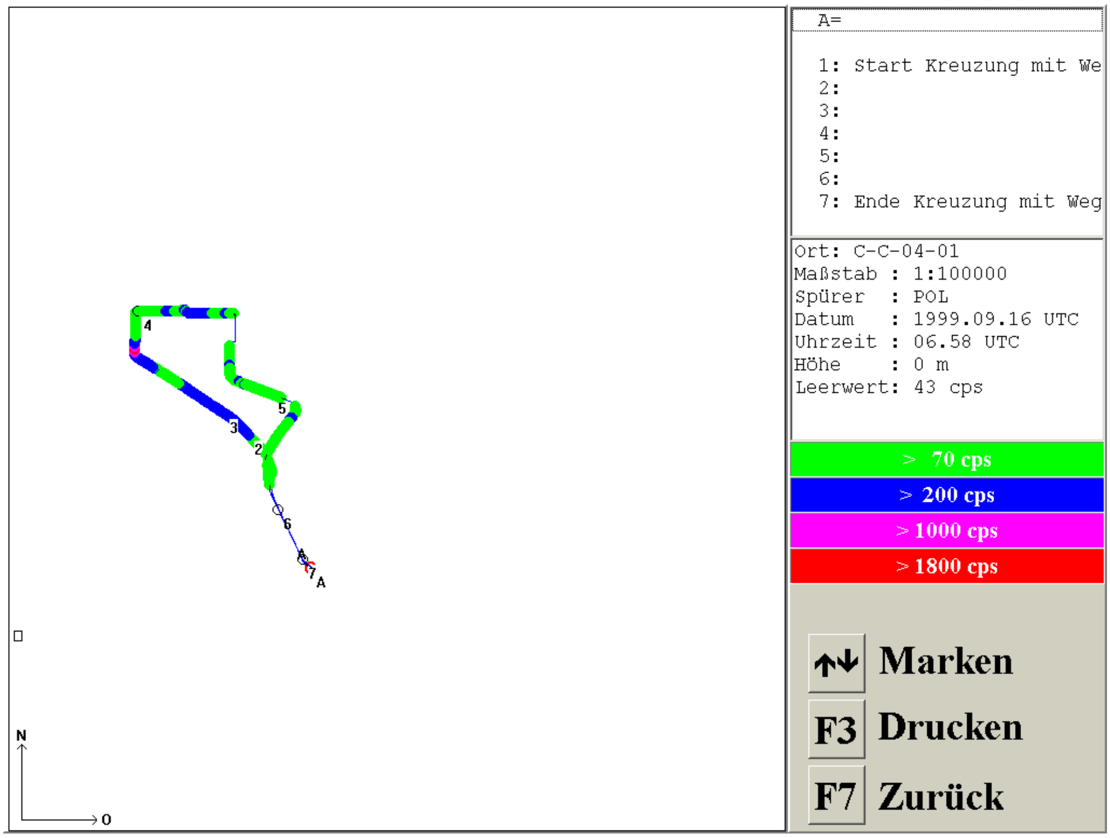
Data analysis

We have got three possibilities to analyse the measuring track:

First a 1:1-overlay for each usable map with four variable count rate colours to produce a stepped radiation picture:

- File name
- Scale
- Officer
- Date and Time (UTC)
- Height
- Count rate of the background (starting point)

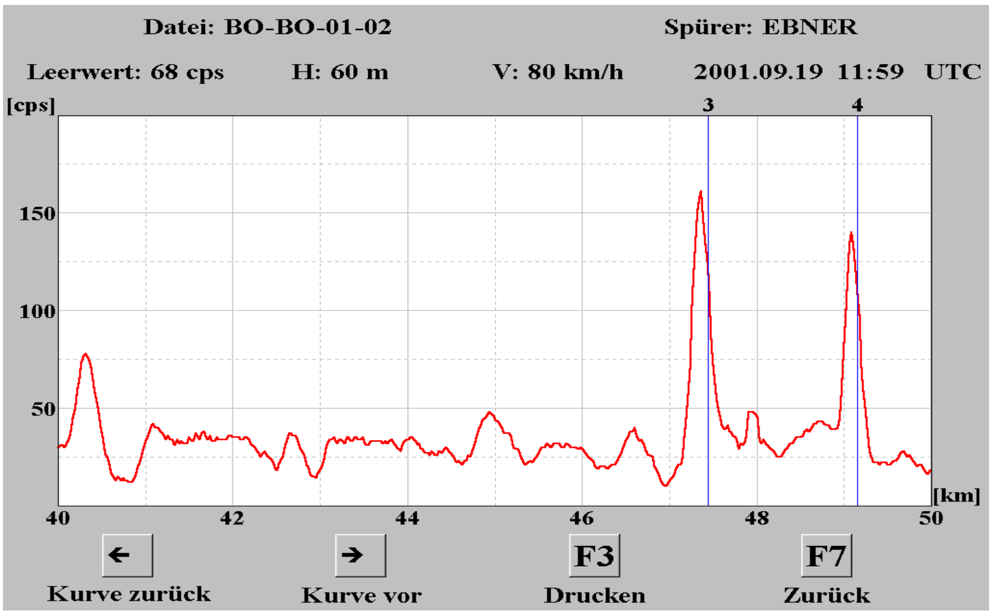
Analysis without digital map (car-borne gamma-search around the sarcophagus of Chernobyl)



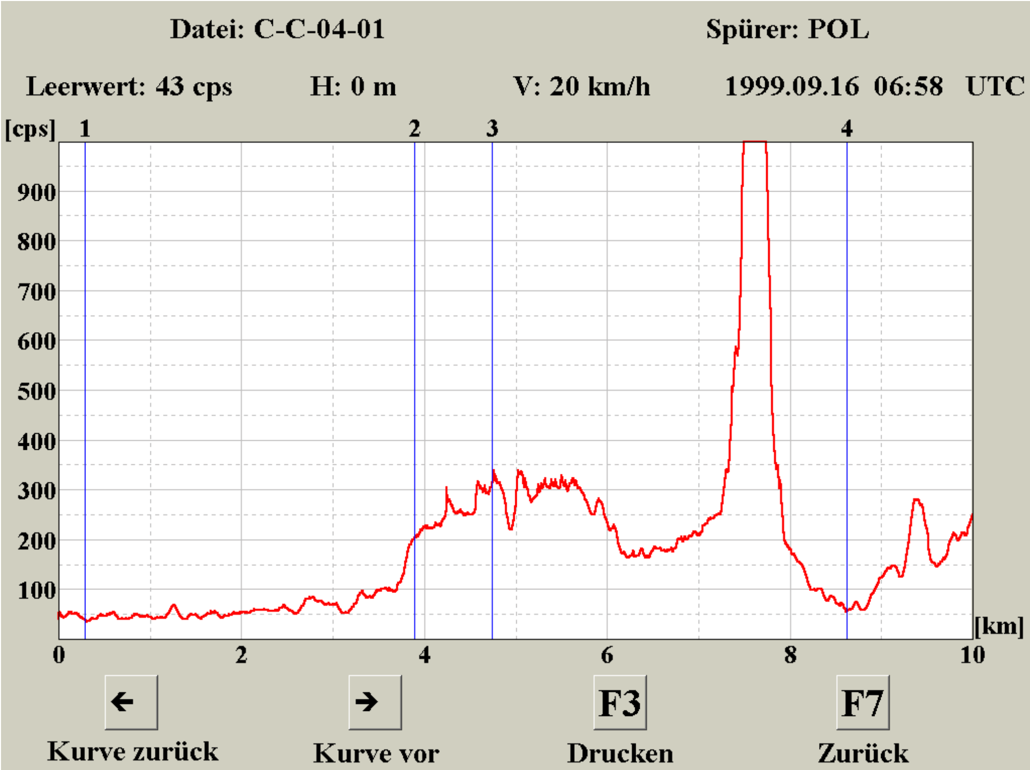
Analysis with digital map (like AGS, Team ATA)

The second possibility to analyse is the count-rate curve with distance in km:

Counts per second depend on distance (area A1)



(Chernobyl)



The third analysis with the table consists of:

- countrate
- position data in WGS84-format and in Austria additional in our national format
- both is saved each second

Table evaluation (Chernobyl):

Lfd. Nr.	Marke	MW >1000 cps	GPS - Koordinaten WGS 84 Format	Bundesmeldenetz Koordinaten	Blatt Nr.	Bezeichnung
0	A		N51°19.9847´E30°8.3556´			....
871		1168	N51°23.0408´E30°4.6125´			
872		1230	N51°23.0510´E30°4.6129´			
873		1338	N51°23.0510´E30°4.6129´			
874		1477	N51°23.0612´E30°4.6132´			
875		1611	N51°23.0612´E30°4.6132´			
876		1721	N51°23.0715´E30°4.6135´			
877		1749	N51°23.0715´E30°4.6135´			
878		1796	N51°23.0767´E30°4.6136´			
879		1904	N51°23.0871´E30°4.6139´			
880		1968	N51°23.0871´E30°4.6139´			
881		2023	N51°23.0922´E30°4.6140´			
882		2093	N51°23.1024´E30°4.6148´			
883		2166	N51°23.1024´E30°4.6148´			
884		2184	N51°23.1129´E30°4.6152´			
885		2047	N51°23.1129´E30°4.6152´			
886		1865	N51°23.1234´E30°4.6154´			
887		1758	N51°23.1234´E30°4.6154´			
888		1755	N51°23.1285´E30°4.6155´			

```
Ort: C-C-04-01
Spürer     : POL
Datum      : 1999.09.16 UTC
Uhrzeit    : 06.58 UTC
Leerwert   : 43 cps
Max. Wert  : 2184 cps
Höhe       : 0 m
```

Tabelle Auf - Ab

F3 Drucken

F7 Zurück

Results

Area C1:

2 of 5 sources have been detected by car (because it was not possible to go in the whole area with the car Ford Transit).

Area C2:

For this area we are not able to present any results because we did no measurements there

Area C3:

The only one source in this area has been detected by car

Area C4:

1 of 7 sources has been detected by car (because it was not possible to go in the whole area with the car Ford Transit).

Area C7:

For this area we are not able to present any results because we did no measurements there

Conclusions

During this exercise we got a lot of practise to take measurements in an area with a high and very different radioactive background.

We met many nice and very helpful people who gave us assistance during this exercise. We really enjoyed our stay in Sweden.

The main advantage of our system is the really short time for being ready to make measurements (about 10 minutes). Although we only can inform the headquarters about the difference to the count rate of the background it is a very useful and important information for urgent decision-finding in the field of radiation protection.

Denmark, team DKK

Danish Team (DKK)

Kirsten Brogaard Juul, DEMA (Navigator)
Geno Møller Pedersen, DEMA (Driver)
Helle Karina Aage, DTU (System operator)

Equipment

The system used by the Danish team is of the same type as the ones used by the Baltic countries:

- 4L NaI(Tl)-detector (16”*4”*4”)
- Exploranium GR320 spectrometer, 512 channels
- Exploranium GR660 software.
- DGPS.
- Exploranium GR130 portable spectrometer

Additional equipment:

- Garmin portable GPS and compass

Detector mounted on the roof at 220-cm height: back of the car, right side.

Size of detector 10.16*10.16*40.64 cm^3. Al-box of 1.5-mm thickness with 2-cm PUR foam. Detector encapsulation 0.25 mm stainless steel. 2s-measurements and stabilisation on ^{208}Tl 2615 keV.

Methods

Purpose / Strategy

The purpose of the Barents Rescue exercise was defined from an *Emergency Management Point of View:*

- Find as many sources as possible as quick as possible.
- Try to recognise source type without spending too much time.
- Calculation of source strength was of lesser importance.
- Co-operation with Danish AGS team when possible.

Search method

The search method was developed during the exercise, as the DKK team was an inexperienced team that had not worked together before (second DK CGS team). The search during the first day (C7) did not go very well. Too much time was spent on minor roads and on roads in bad conditions. After the first day it was clear that it was impossible to cover more than 50-60 % of the search areas because of size and road conditions.

It was decided to skip doubtful roads (the 2-wheel drive car could not cope with too difficult terrain) and minor roads without heavy track marks that could indicate transportation of a source / shielding material. Also the team navigator was on the lookout for suspiciously looking buildings or vehicles independent of the operator.

Driving speed

For optimum performance a driving speed of 40-50 km/h was hoped for. This turned out not to be possible. The driving speed varied from 15 km/h to 50 km/h due to different types of road conditions.

The first day in area C7 the driving speed on good roads upon leaving the area was up to 70-80 km/h in order to leave the area on time.

Data analysis

On the road: source identification

During the search the data were analysed with Exploranium GR660 software. While measuring it is possible to see colour plots (rainbow) of the spectra, the latest measured 2s-spectrum and window count rates for selected channel windows. These functions each occupy a window and only one window can be seen at a time. It is possible to set up the system to show stripped window count rates, however, only a certain number of windows can be defined. Four energy windows can be displayed at the same time. It was chosen to use a high-energy window (K), a ^{137}Cs window and two low- energy windows. It was then possible to tell whether an increase in the number of counts in e.g. the low energy window seemed source related or more likely related to an increase in the K-window. (It was chosen for the K-window to display non-stripped count rates, therefore also contribution from U and Th could be found in this window.)

The Exploranium software has no alarm function and it is not (yet) possible to view stripped spectra. Thus source observation depends solely on the skills of the operator. A new software version has just been discussed.

Figure 1 and Figure 2 show examples (different windows) of increases in stripped count rates (K-window not stripped!) Figure 1 shows an increase in the caesium window together with an increase in the low energy-windows. This source was unshielded. Figure 2 shows an increase in the low energy windows only. This source was shielded.

On the road spectrum stripping

The stripping factors (approximates) for some low energy windows were calculated from measurements performed in Boden during the pre-exercise day prior to the start of the exercise itself.

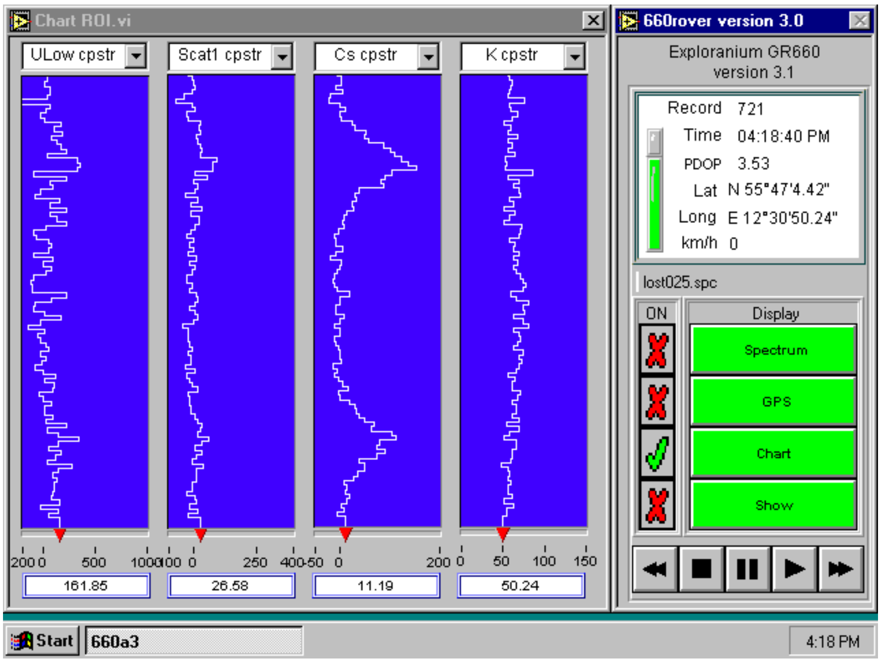


Figure 1. Unshielded ^{137}Cs source (passed twice).

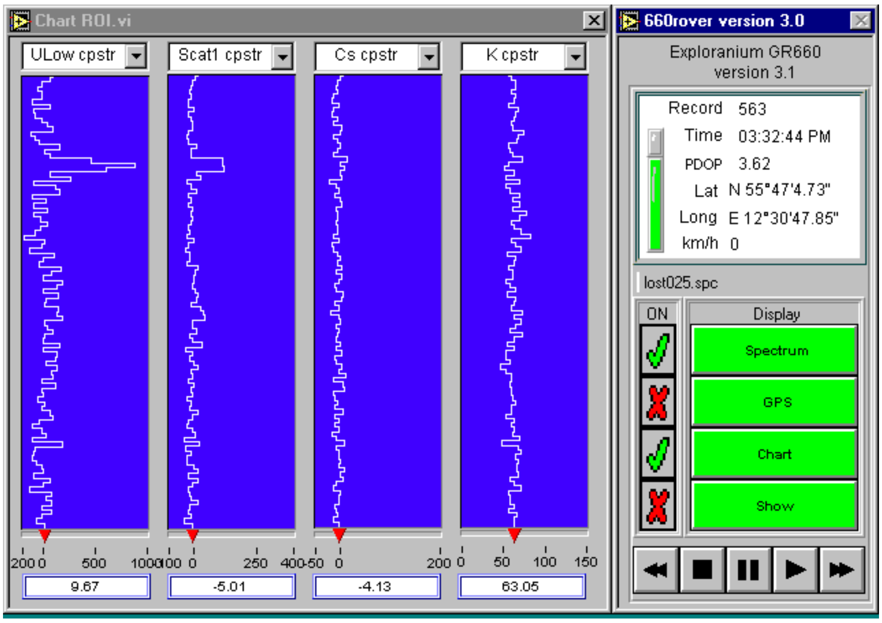


Figure 2. Shielded ^{137}Cs source.

Off the road: source identification

In case of shielded or partly shielded sources it may not be possible to identify source type from the CGS measurements due to not being able to get close to the source with the equipment. Therefore an Exploranium GR130 portable instrument was used, too. It can show dose rates, count rates and 256-channels gamma-spectra.

Sometimes the peak identification was made only from GR130-measurements and sometimes this was not enough, either.

On the road: calculation of distance from full energy peaks

When passing a source at constant speed the relation between distance to source, r, and FWHM is approximately:

350 keV	r = 0.69 FWHM (m)
662 keV	r = 0.65 FWHM (m)
1250 keV	r = 0.59 FWHM (m)

A calculation of the function of FWHM (m) in relation to distance to source was made during calibration of CGS equipment for equivalent surface activity of ^{137}Cs, where the calibration took place in Næstved, Denmark, and was based on fixed car-position measurements on a point source placed at 800 different positions. Also calculation of absolute detector efficiency versus distance was done for the calculation of source strengths.

Figure 3 shows stripped count rates from an unshielded ^{137}Cs source passed twice. 2s-measurement time, car speed 2 km/h, distance 17 m and source strength 16.5 MBq.

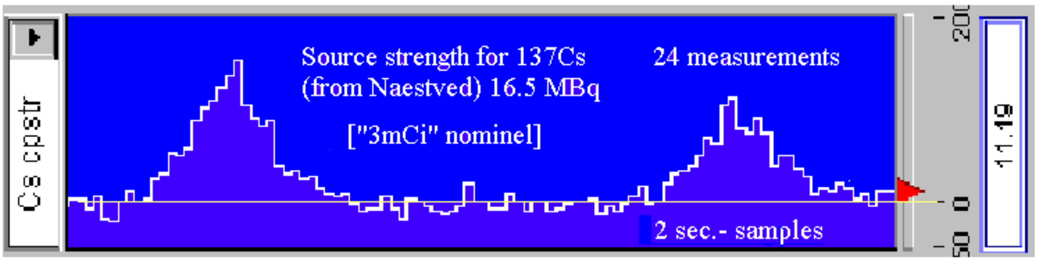


Figure 3. Calculation of distance and source strength.

FWHM: 2s*24*2 km/h = 26.7m. Distance: 0.65*26.7m = 17.3 m. Maximum count rate: 100 cps. Source strength: 100 cps/ 0.629 counts/γ = 15.90 MBq (using absolute detector efficiency as a function of distance).

The team spent the pre-exercise day testing this method - when a source was found one should drive slowly past it to find the FWHM. Already at the calibration area it turned out that there were problems due to non-uniform shielding of sources. As the exercise turned out, it was not possible to use the above-mentioned method. The car speed was too variable and often no full energy peaks could be detected. Most distances were estimated visually if the source could be seen or from a number of GR130 air kerma rate measurements.

Off the road: source strengths from air kerma rates

It was too difficult to estimate source strengths from the CGS measurements. Instead the GR130 instrument was used with a portable GPS to at least give some air kerma rates closer to the source and from different directions to the source.

Only one estimate of source strength (3:1) was performed during the exercise. Result: 10 GBq versus 20GBq. Source 3:1 was a composite of 4 ^{60}Co sources but was not identified as such.

No further calculations of source strength have been made. It is planned to re-evaluate the air kerma rate measurements when information on source shielding material is available to test scientific methods because different types of shielding is a problem in general.

Post-processing: MapInfo and NUCSpec with NASVD

The data were analysed later with the NUCSpec software that includes facilities for NASVD processing. This data analysis has to be done on a different computer than the one used in the car. It was not possible (time and personnel related) to do this until in the evenings after the searches were done. From NASVD processing it is possible to reconstruct single measurements with noise removal – or one can just analyse the general shapes found in the series of measurements. Also SDI air kerma rates were plotted on a map and additional stripping factors were calculated.

Results

Sources found and not found

Table 1 shows which sources the Danish CGS team found. For sources not observed, the closest distance to source has been calculated from DGPS readings. No consideration has been taken to the fact that the car sometimes seems off track compared to MapInfo maps (East direction, interference from airwing?). Some sources were observed as “suspicious” measurement points during the exercise but were not reported. They have later been recognised as sources. Also some sources were reported as wrong isotopes.

Source 1:2 was initially reported as ^{133}Ba due to peak identification of two gamma energies close to high intensity barium peaks, 87 keV and 361 keV while on the scene. The measurements were difficult to deal with because of spectrum drift upward due to high count-rates. Later further peaks were identified and source type changed to ^{131}I.

Figure 4 shows spectrum component S1 from NASVD processing of the data file including measurements on source 1:2. The spectrum is almost a real environmental iodine spectrum.

Source 2:4 was investigated on foot because of a small increase of low energy counts. The team soon learned to search for changes in scattered radiation instead of full energy peaks. The air kerma rate increased when approaching a house. No isotope fingerprints were found and the source was dismissed as “interesting” but probably caused by building materials. A major difficulty of the exercise was the frequent changes in natural background that caused several “false alarms” due to naturally occurring anomalies. However, those alarms had to be taken seriously considering the possibility of finding a ^{226}Ra source.

Table 1. DKK identified and not identified sources.

Source	GBq	No.	Found	Comments
^{60}Co	5	**1:1**	**Y**	
^{131}I	9.25	**1:2**	**Y**	First reported as ^{133}Ba, changed to ^{131}I
^{60}Co	5	**1:3**	**Y**	
^{60}Co	5	1:4	N	Closest distance 449 m
^{60}Co	5	**2:1**	**Y**	
^{60}Co	5	**2:2**	**Y**	
^{99}Mo	3.1	2:3	N	Missed, closest distance 80 m
^{99}Mo	18	**2:4**	**N**	"Hunt" at private quarters. Not reported.
				Closest distance 147 m
^{137}Cs	3*0.5	2:5-1	N	Closest distance 490 m
^{60}Co	3*0.02	2:5-2	N	Closest distance 490 m
^{241}Am	0.0004	2:6	N	Missed at 5m-distance….
^{137}Cs	2.6	**6:1**	**Y**	Calibration source
^{60}Co	5	**6:2**	**Y**	Calibration source
^{60}Co	4*5	3:1	Y	
^{137}Cs	0.4	**4:1**	**Y**	
^{137}Cs	2.5	**4:2**	**N**	Suspicion. Measurements on foot. Post-identification. Not reported. 106 m
^{192}Ir	13	4:3	N	Suspicion. Closest distance 281 m
^{60}Co	5	**4:4**	**Y**	Reported as ^{192}Ir, paper mistake
^{60}Co	5	**4:5**	**Y**	Reported as ^{192}Ir, paper mistake
^{137}Cs	1.3	**4:6**	**Y**	What happened to SIR-source type?
^{137}Cs	1.9	4:7	N	Closest distance 217 m
^{60}Co	5	7:1	N	Missed, closest distance 479 m
^{60}Co	5	7:2	N	Missed, closest distance 177 m
^{60}Co	5	7:3	N	Missed, closest distance 93 m
^{60}Co	5	7:4	N	Missed, closest distance 67 m
^{60}Co	5	7:5	N	Missed, closest distance 21 m
^{226}Ra	Nat.	7:6	N	Missed at 6m-distance….
^{226}Ra	Nat.	7:7	N	Missed, closest distance 418 m
^{226}Ra	Nat.	7:8	N	Missed, closest distance 45 m

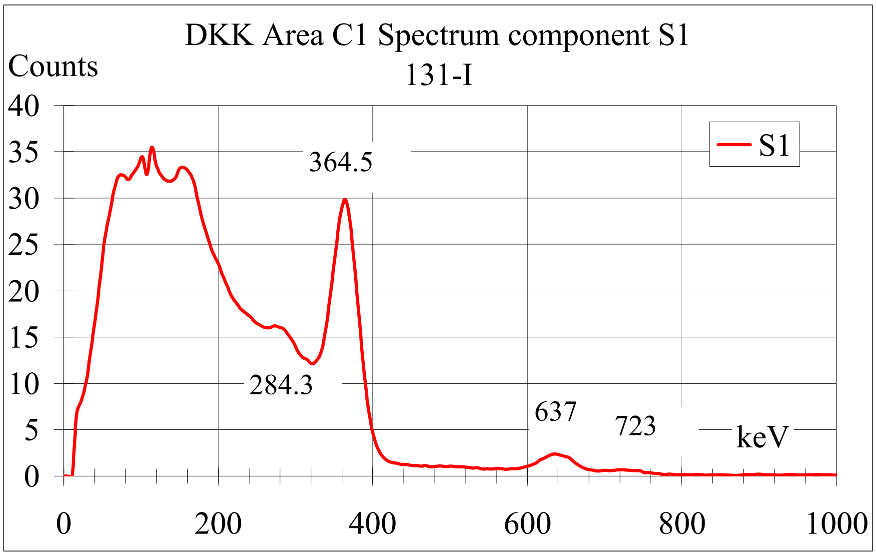


Figure 4. Source 1:2. 9.25 GBq ^{131}I.

The sources 4:4 and 4:5 could not be identified as ^{60}Co on the scene. The SIR-reports were filled in without the source type intending to put in the source type upon delivery of the paper SIR-reports. However, they could not be identified in post processing with NUCSpec either because of lack of full energy peaks.

Figure 5 shows some measurements of those ^{60}Co- sources. In Figure 6 are shown the first two spectral components from the NASVD processing (sources 4:2, 4:3, 4:4 and 4:5 in file). In S2 - right axis - one notices a ^{137}Cs signal around channel 110 (source 4:2) and in S1 - left axis - a very dominant scattered signal

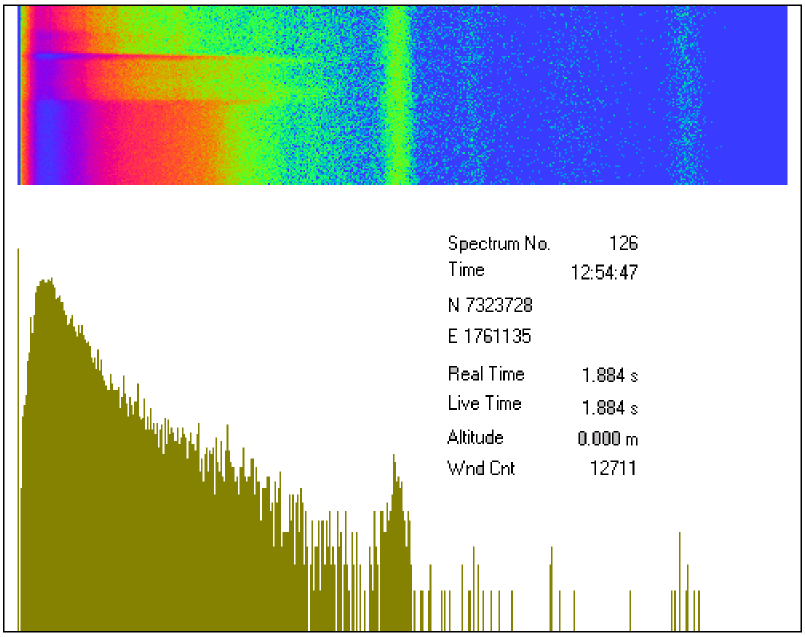


Figure 5. Scattered photons from ^{60}Co source (NUCSpec).

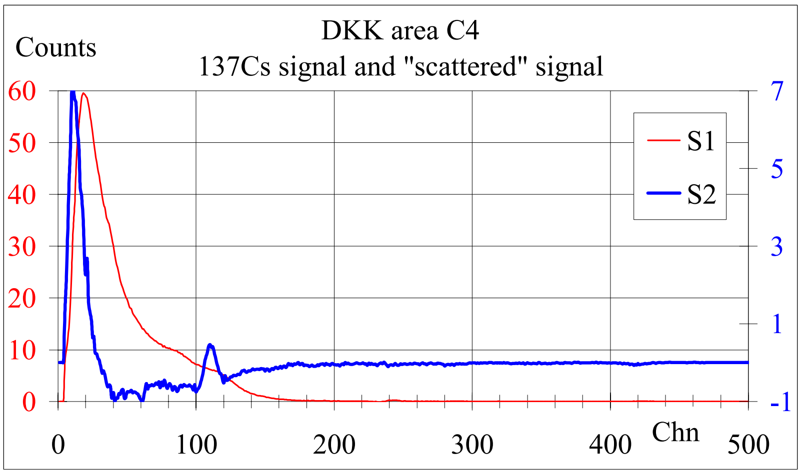


Figure 6. Spectral components for file brb029.spc.

Analysis performed after the exercise shows that those sources had a high probability of being ^{60}Co. After a recalculation of stripping factors for the file in question a small peak in the cobalt window was seen, Figure 7.

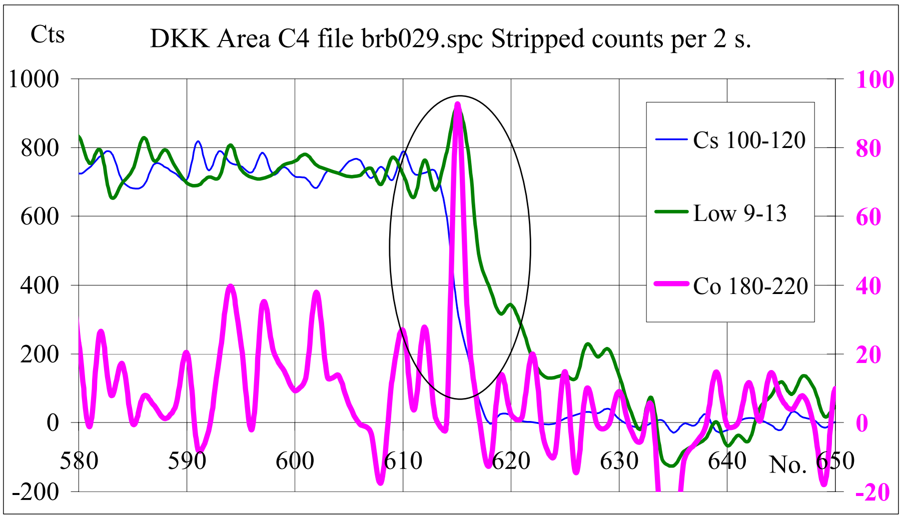


Figure 7. Stripped count rates for different energy windows.

The sources were reported as ^{192}Ir by mistake due to filling in the isotope types in the last minute. During the search in area C4 the team was co-operating with the AGS team that had spotted this isotope and the CGS team went to investigate this. At the scene suspicion arose and the source was thought to be possibly caesium. The papers were filled in but this source was never reported by telephone. A post-processing of data at REAC showed a possibility of caesium and possibly something else. The source(s) was not reported. However a mix-up of SIR-reports occurred and the two unknown sources found in this area (sources 4:4 and 4:5 were erroneously reported as the suspected ^{192}Ir source instead of heavily shielded unidentified sources.

After the exercise the possible iridium and/or caesium source was identified as ^{137}Cs. Figure 8 shows a NUCSpec view of this source that was not possible to see on the CGS equipment. The arrow shows source position.

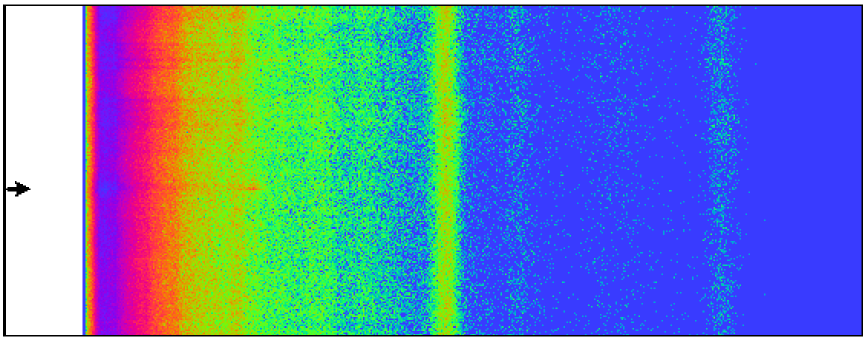


Figure 8. Caesium source 4:2 at arrow.

Figure 9 shows the track lines for DKK. The source locations were plotted on the map to identify in which files (26 files) additional information might be found). It is seen that some of the sources the team drove right by without noticing. This is especially true for area C7 where the team started with a thorough search in the Southern part of the area and spent a long time without finding anything. At the Northern end where most of the sources were located the team was speeding to get out of the area on time.

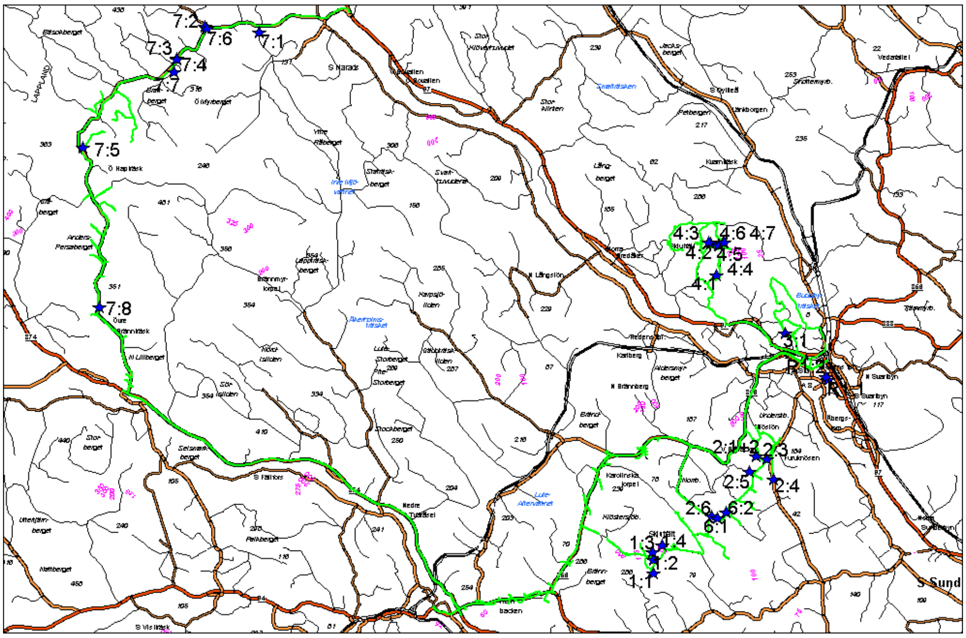


Figure 9. Track lines and source positions, MapInfo.

Figure 13 and 14 show SDI air kerma rates. Most “hot spots” in area C7 were actually caused by natural environmental isotopes, Figure 10.

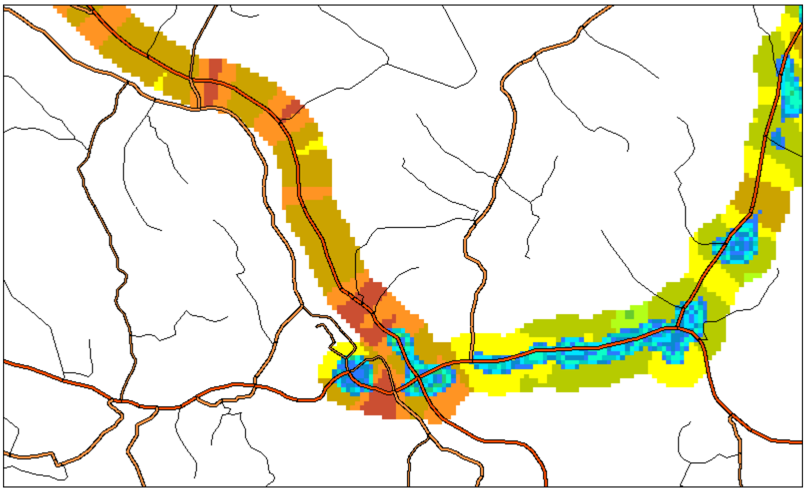


Figure 10. False alarms in area C7 at dark brown spots.

A first post-processing of the data for area C7 during the exercise did not show any signs of missed source signals. A second post-processing of data after the exercise did not reveal source 7:5 (^{60}Co) or source 7:8 (^{226}Ra) either (files brb011 and brb010).

Post-processing of file brb012 (7:1, 7:2, 7:3, 7:4, 7:6 and 7:7) with new stripping factors indicated the possibility of a ^{60}Co source around spectrum no. 637. Comparison of co-ordinates show that this might be source 7:3 or 7:4. Source 7:2 should have been seen around no. 792, if present. Please confer Figure 11 and Figure 12. (Energy calibration: 662 keV in channel 110, 2615 keV in channel 418.)

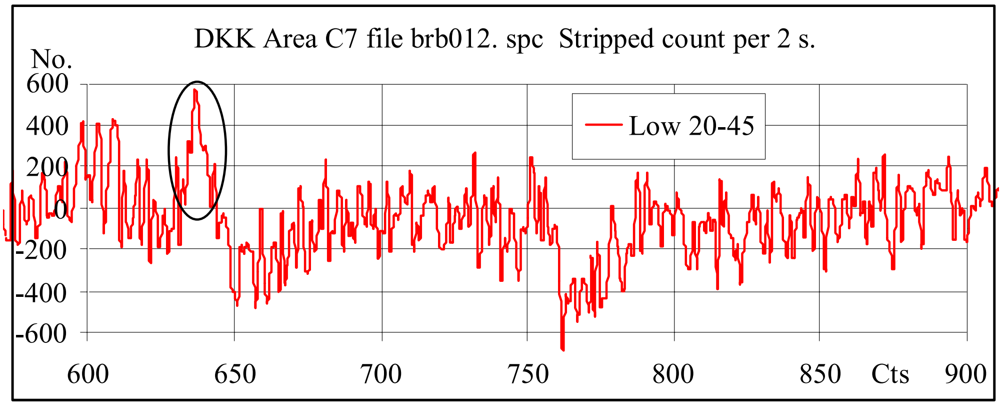


Figure 11. Stripped counts in low energy window.

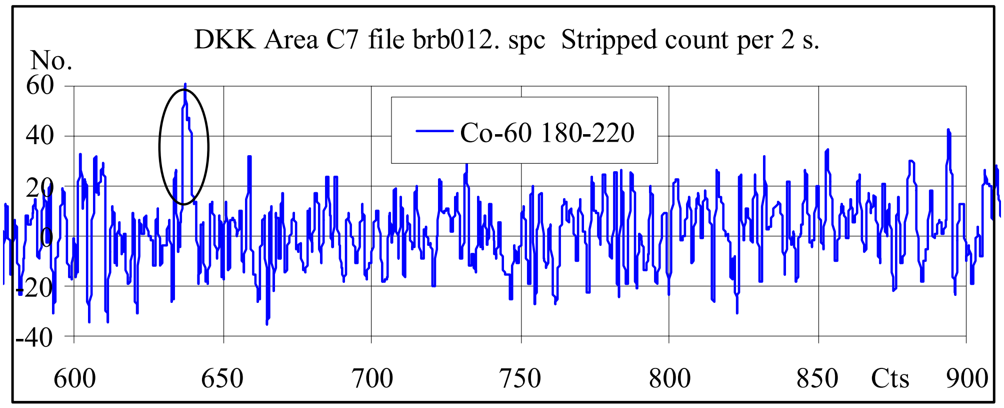


Figure 12. Stripped counts in cobalt window.

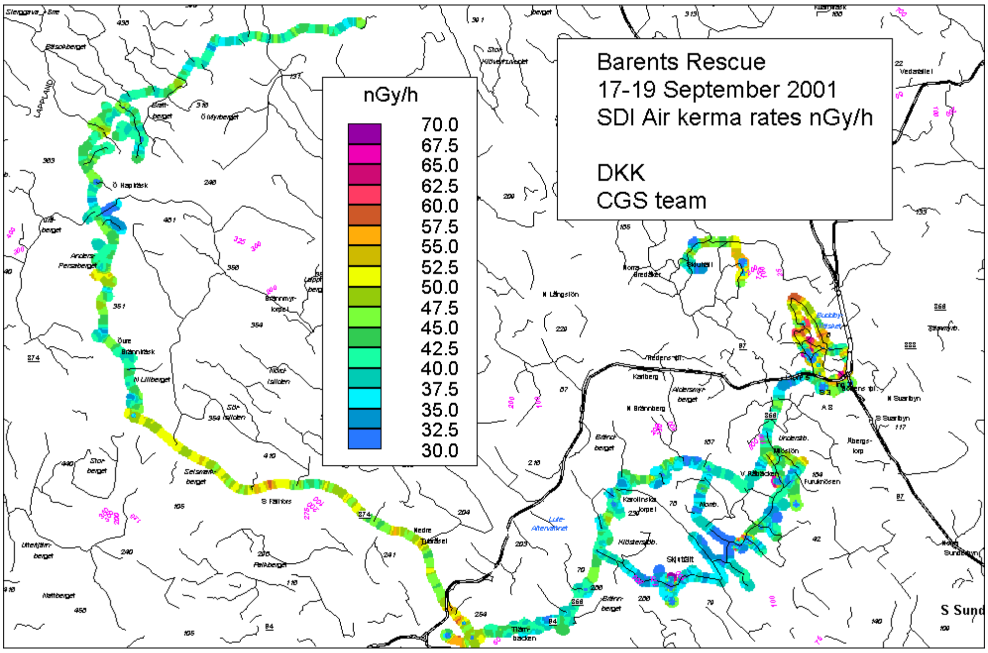


Figure 13. SDI CGS air kerma rates for DKK. Continued in Figure 14 due to limited number of pixels on map. (Also SDI air kerma rates driving to and from the areas can be seen.) MapInfo.

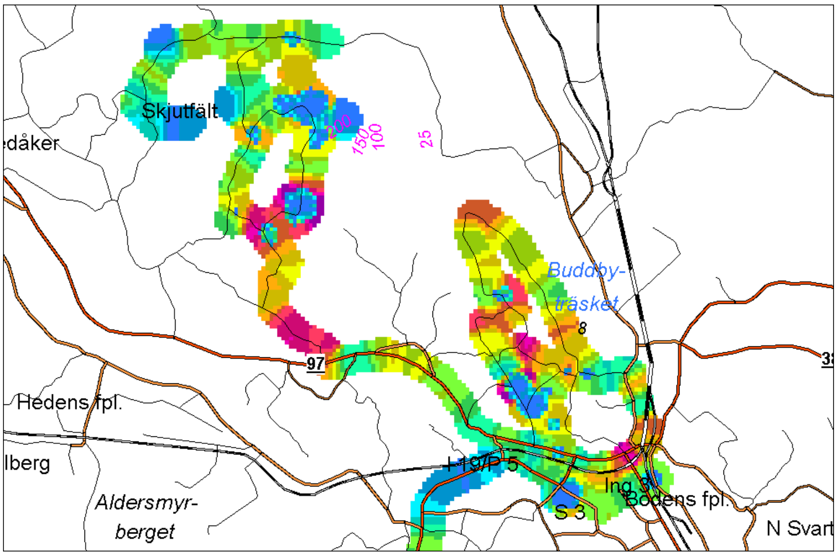


Figure 14. SDI CGS air kerma rates for DKK, continued. MapInfo.

Conclusions

For the DKK CGS team participation in the Barents Rescue exercise has been a valuable experience.

The team had very little practical CGS fieldwork experience on arrival and had never worked together before. The pre-exercise day therefore was spent on calculation of stripping factors and testing calculation methods.

The first day of the real exercise was spent mainly on gaining experience regarding optimum car speed and search strategies. Also the tasks of the individual team members were worked out at this time. At the end of the exercise the team had gained a lot of experience and found most of the γ-sources passed within a reasonable distance. Though, some of them were not reported, most were in fact successfully investigated as “suspicious” and in that sense also found.

Regarding the identification of source types the theoretical background was mostly related to unshielded sources. The team gained a lot of information on spectral shapes describing what sources do look like in environmental surroundings – especially regarding shielded sources. A new search strategy for shielded sources was developed during the exercise.

In the “on the road” processing and post processing of data it was found that the set-up of the CGS system could be improved. This is true especially for the setting up of colours on the monitor and not the least for calculation of stripping factors for use while measuring. It was found that in surroundings with frequent changes in the contents of natural isotopes and landscape geometry it is necessary (during post-processing) to perform a calculation of stripping factors for each area in question.

For the calculation of source strengths future work will need to be done. The methods brought to the exercise were not sufficient for the way the exercise was performed. When dealing with sources not uniformly shielded at all side’s difficulties were encountered and it was concluded that the source strength could not be calculated solely from the CGS measurements (at present).

With this new experience at hand, in case of emergencies the new CGS team could now function on its own which means that in the future Denmark now can use two CGS teams.

Acronyms

CGS	Carborne Gamma Spectrometry
DEMA	Danish Emergency Management Agency
DTU	Technical University of Denmark
NASVD	Noise Adjusted Singular Value Decomposition
SDI	Spectrum Dose Index

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Bargholz, K.: Dose rate and nuclide mapping from airborne and ground based gamma-ray instrumentation. Ph.D. thesis. Ørsted-DTU, Section for Measurements and Instrumentations Systems, Technical University of Denmark, April 2001.

Aage, H.K., Korsbech, U. Bargholz, K.: Determination of Carborne Gamma-ray Spectrometry Sensitivities for ^{137}Cs. Department of Automation, Technical University of Denmark. Report IT-NT-53, October 2000.

Bargholz, K., Hovgaard, J., Korsbech, U.: Standard methods for processing data from the Danish AGS system. Report IT-NT-36, Department of Automation, Technical University of Denmark, April 1998.

Aage, H.K., Korsbech, U., Bargholz, K., Hovgaard, J.: A new technique for processing airborne gamma ray spectrometry data for mapping low level contaminations. Applied Radiation and Isotopes 51, pp. 651-662, 1999.

Korsbech, U.: DOS PC-programs in the language “Basic” for calculation of area specific stripping factors.

Estonia, team EEK

Estonian Team (EEK)

Eia Jakobson
Larissa Palmin
Aldo Tera

Equipment:

NaI(Tl)-spectrometer	Exploranium GR-660
Volume	4 l
Multichannel analyser	Exploranium GR-320
No of channels	512
No of spectra per minute	30
GPS type	DGPS
Coordinate system	WGS 84 and RT 90
Dose rate instrument	Exploranium GR-130, volume 1.5 inch, 256 channels

Methods:

Driving speed: 30-50 km/h

Detector height: 2m on the roof of the car

Search method: reading of a spectrum

Data analysis:

Source recognition: according gamma peak energy

Identification: mostly by spectrum & by hand-held spectrometer

Location: using car coordinates

Nuclide source strength: By calculations depending on gamma dose rate & distance & gamma constant

Results:

We represented our data only in .nks format. Reports were also made electronically.

Maps are represented on the Barents Rescue homepage.

Area	No of sources in the area	No of sources located by EEK	Sources identified by EEK	Remarks
C 3	1 Co-60 source	1 source	1 Co-60 source	The same source was reported to REAC two times
C 4	4 Cs-137, 2 Co-60 and 1 Ir-192 sources	3 sources	1 Cs-137, 1 Co-60 source	1 source was wrongly reported, but this place has higher background.
C 1	3 Co-60 and 1 I-131 source	2		I-131 was unidentified, but energy of peak was reported.
C 2	4 Co-60, 2 Cs-137, 1 Am-241, 2 Mo-99 sources	4 sources	2 Co-60 and 1 Cs-137 sources	
C 7	5 Co and 3 Ra-226 sources	5 sources	5 Co-60 sources	

Conclusions:

Team EEK got a lot of good experiences of finding real sources.

Finland, team FIK

Finnish Team (FIK)

Jarkko Ylipieti, Tarja Ilander, Mikko Leppänen

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Equipment

Toyota 4Runner

Normally the car is in ready for immediate use at the Regional Laboratory in Northern Finland (Figure 1).

Dose rate instruments

Geiger Müller Tube RD-02L (Figure 2)

RDS-200 survey meter (Figure 3)

TSA search meter

Laptop

Dell Latitude C600

Installed software:	desktop mapping MapInfo
	dose rate mapping Sahti

Navigation

IMTEC Supported model 5 GPS receiver with Trimple antenna

Magellan 315 GPS Navigator

Communications

GSM and NMT mobile phones

PCMCIA card for data sending (not used in the exercise)

Additional

provided by the organiser:

Personal dosimeters, paper and digital maps, radiophones

Methods

The crew consisted of three members. One of the members was the driver, one operated laptop, and the third monitored the dose rate instruments.

The strategy in the large area was to drive at least along all the main roads but, also gravel roads in order to avoid driving along same road twice. However, the flight data proposed a route if one was available. The average speed was about 30km/h, but rose to 60km/h if the road or the search area ended and we had go back to the same road. During the first day we were in a hurry to get out of the area in time, so the speed in the rest of the area was close to the speed limit, 90km/h.

Digital maps of the exercise area were registered in the desktop mapping software (MapInfo), and the directory where the maps were located was instructed to dose rate the mapping software (Sahti). Sahti obtained the positions from GPS satellites and located us on the registered maps. As these coordinates were updated every 5 seconds, we always had our correct position. This was important because the areas were large and the time available for each area was short. There was no time to get lost.

The TSA search meter was set to alarm when the counts, which exceeded the natural background. During the drive the natural background level varied according to the terrain; in the low natural background area the alarm level should have been lower than that in the high natural background area. Whenever the TSA search meter alarmed, we reduced our speed and checked the dose rate. Whenever the dose rate was close to or over 0.20 µSv/h, we get out of the car and investigated the reason for the elevated dose rate. Naturally buildings and stopped vehicles were suspected, but sometimes there were no buildings or other suitable targets to check. The exposed cliffs and rocky terrain frequently triggered an alarm in the TSA search meter.

One useful method was to use the flight data prepared the day before. Flight data reported by the Finnish AGS team (FIA) were used very effectively on one day.

On the last day of the exercise we noticed that all the sources were marked with a white pole. This information helped us to find one source - the pole was visible from the road we were driving along, and the source was hidden in the forest about 100 m from the road.

Data analysis

When we located the source, we measured the dose rate surrounding the point in at least four directions with the RDS-200. The directions and dose rates were marked on the Source Identification Report (SIR). The source was also marked on the desktop mapping software as a symbol, from which we transferred the coordinates in RT-90 format to the SIR. If we were not able to get the car close to the source, we obtained the coordinates from the handheld GPS receiver.

Results

We found four sources during the pre-exercise day, and eleven sources and one extra source during the exercise days. The dose rate from the Sahti is indicated in yellow boxes on the maps. More detailed dose rates were reported in the Source Identification Reports.

Area C7

Area C7 was very large (Figure 4). We drove 200 km in eight hours and found five sources. We also reported one source, which was not the correct one. It was a cardboard box that triggered an alarm in the TSA search meter and the RDS-200 measured 0.5 mikroSievert/hour. We reported this because our equipment reacted. The rest of the sources were hidden in military storage buildings. One source was not found because of the lack of time.

Areas C1 and C2

We obtained these (Figure 5) source locations from the flight team (FIA). As the coordinates were rather exact, we did not have any problems finding the sources (Figure 6). We were not able to get the Sahti (and Sahti GPS) near to one source because it was not accessible by road. The coordinates from the FIA were entered on the handheld GPS, and the RDS-200 was carried to the source by foot.

Areas C3 and C4

Area C3 (Figure 7) was rather monotonous. There was only one source in the large green building. We did not have any flight data available for area C4 (Figure 7). In area C4 we found four sources, one of them even though it did not register on our equipment. We happened to notice the white pole, which led us to the source.

Conclusions

At the beginning of the planning exercise we had reserved only two persons for the team. In the pre-exercise we had a third member and this proved to be necessary.

Sahti (RD-02L) was very useful for navigating, but it was too slow to detect point sources from a moving vehicle. Sahti requires a slow driving speed on order to obtain enough counts to calculate the dose rate. The more sensitive device (TSA search meter) was very useful.

The exercise was very interesting and it gave us a lot of experience that will be of great benefit in the future.

Figure 1. Toyota 4Runner.

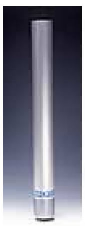

Figure 2. Geiger Müller Tube.

Figure 3. RDS-200 survey meter RD-02L.

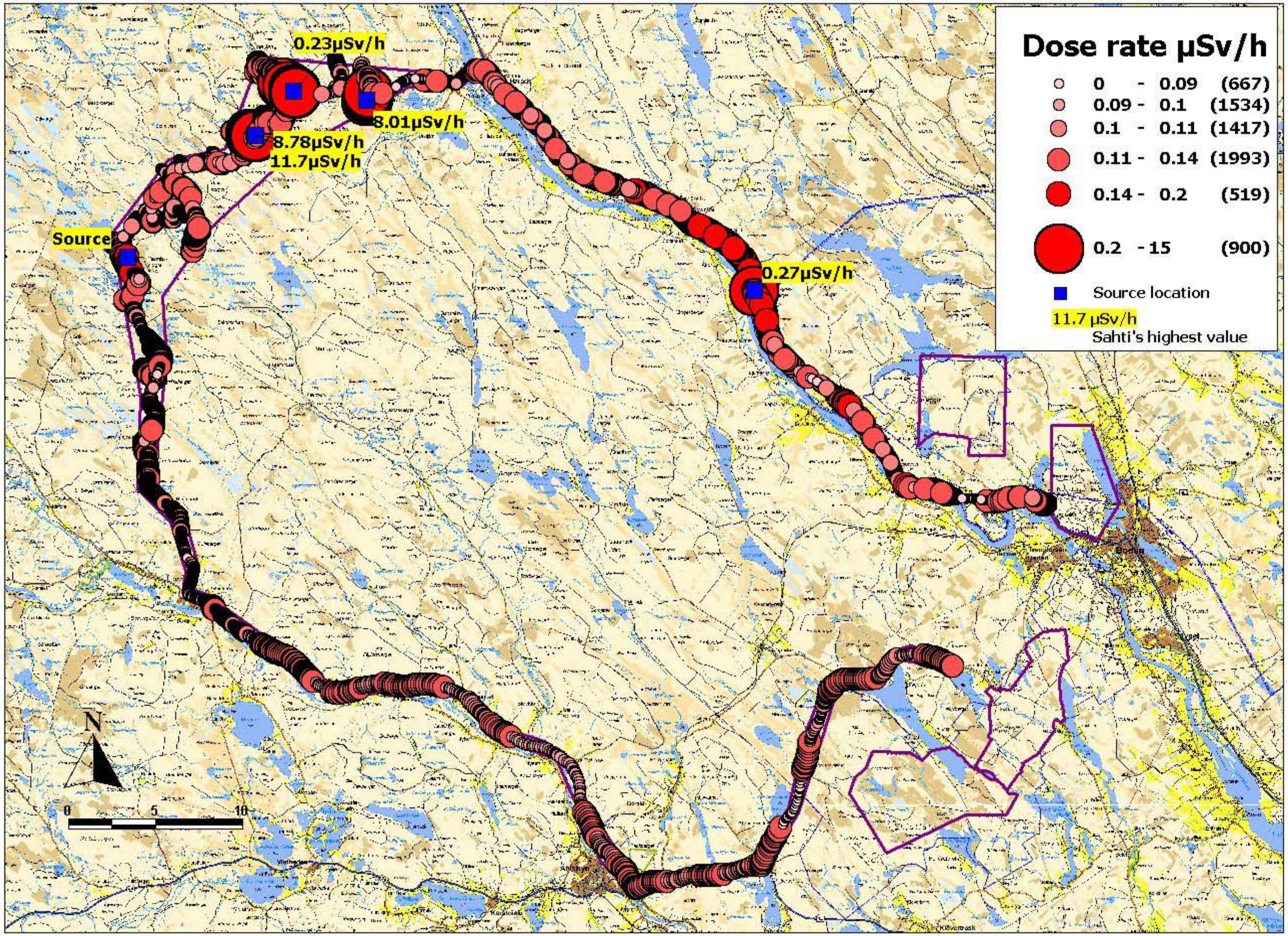

Figure 4. Area C7

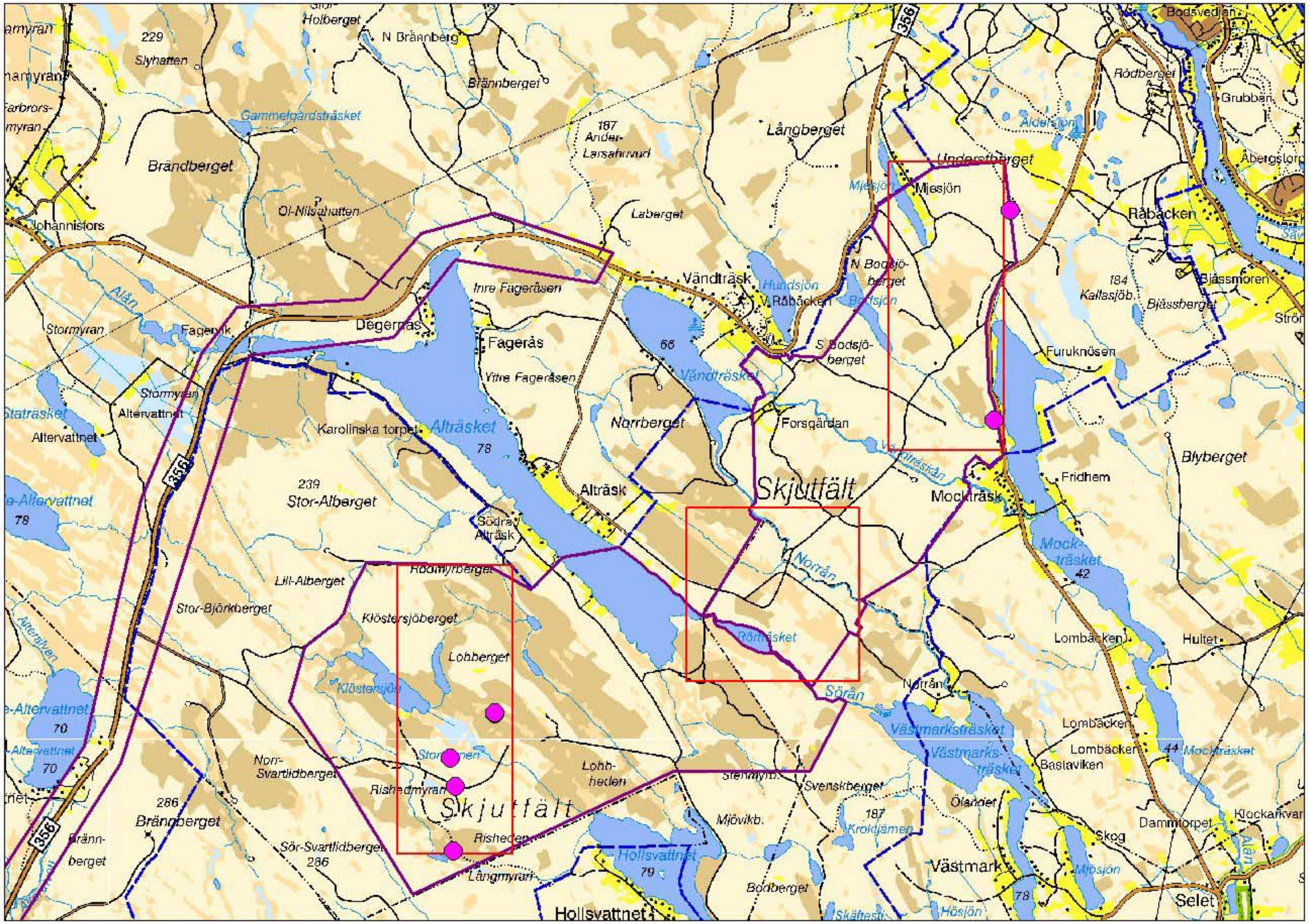

Figure 5. Flight data

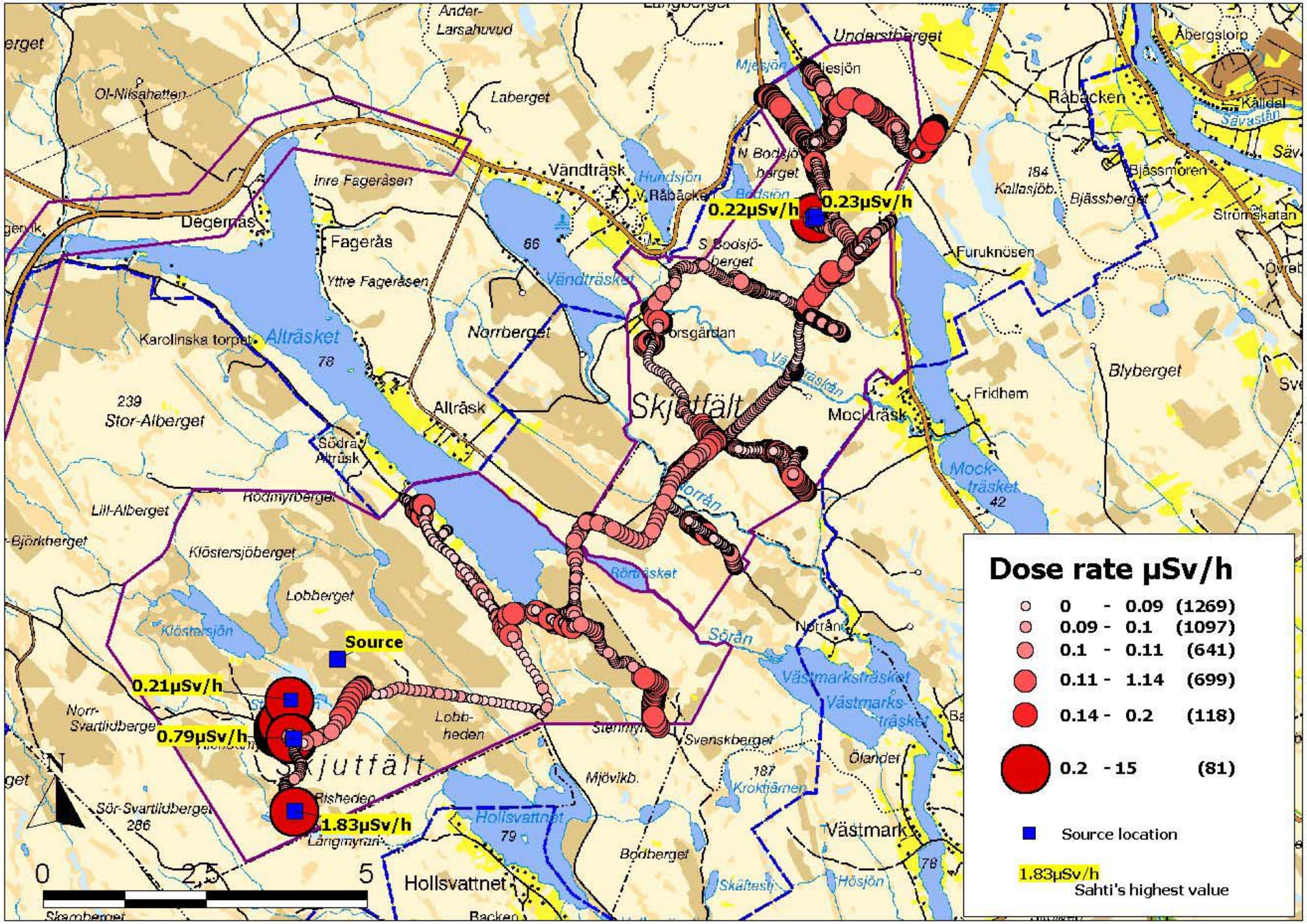

Figure 6. Areas C1 and C2

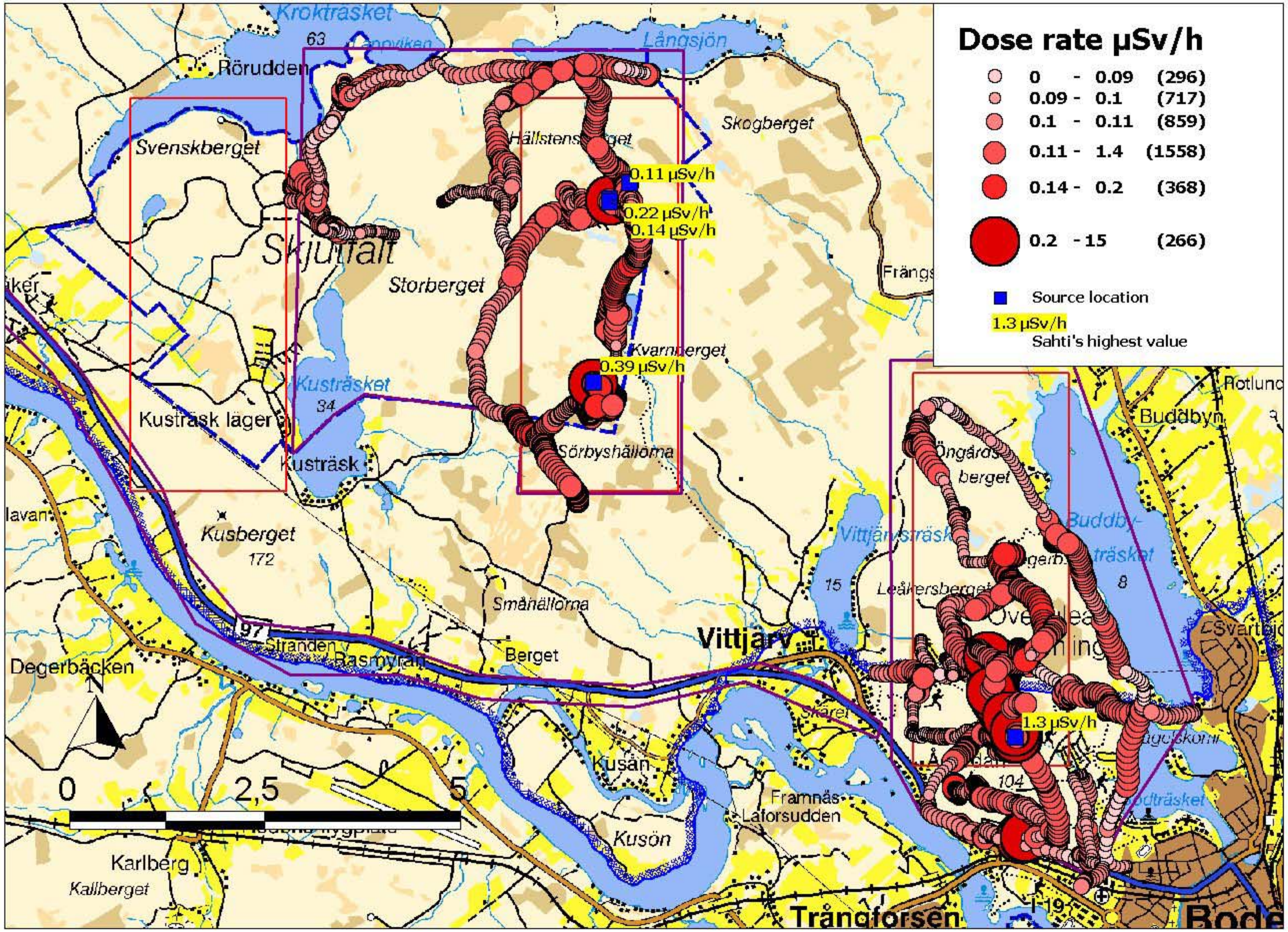

Figure 7. Areas C3 and C4

Finland, team FIL

Finnish Team (FIL)

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Equipment

The Finnish moving radiation measurement laboratory is built into a VW Transporter Syncro with a heightened roof. The laboratory is in constant preparedness and is deployable within one hour of the arrival of the crew. In its standard form the laboratory is equipped with the following:

- Air sampling unit (not used in LIVEX)
- Rigidly mounted Gamma spectrometry detector (Ortec standard P-type 35 % HPGe, Nomad gamma spectroscopy unit (MCA+HV supply +linear amplifier)
- Pressurised Ionisation chamber (PIC, Reuter Stokes RS-112)
- Dose-rate meter GM Rados RD-02L (spare for PIC, not used in LIVEX)
- Dose-rate meter Alnor RDS-120 (with Beta Probe)
- Trimble GPS (not differential, serial signal dividable to three computers)
- Three networked computers:
- Dose rate mapping, Sahti Software (STUK)
- Mobile gammaspectrometry, Sampo Software (Doletum Oy)
- Data communication
- GSM and NMT-450 phones
- UPS
- 220 V, 3.5 kW Car Power system
- Personal dosimeters (not used in LIVEX)
- Gas-masks and overalls (not used in LIVEX)

Additionally, during the LIVEX excercise we had with us

- Portable gammaspectrometry unit (19% HPGe, Nomad and portable computer)
- TSA scintillation detector mMCA-430 1" (dia) x 2" (height) NaI(Tl) Scintillation detector

For the exercise we also equipped the gammaspectrometer with a simple angular search device consisting of a scale of degrees and some lead bricks. As a preparation for the exercise we also made excel-sheets for point-source activity and dose rate calculations. These additions will be part of the standard equipment of the laboratory in the future.

The maps used during the exercise where provided by the organiser. The paper and digital maps where scarce on detail that would have been desired for route planning and source location. In our navigation software we used the provided raster map in MapInfo RT90 format and plotted the GPS data (WGS84) onto the map. The map co-ordinates fitted well with the GPS-data (Fig. 2)

Methods

The main search instrument in the vehicle was the 35% HPGe detector. It is rigidly mounted in a standing position (facing upwards) approximately in the middle of the vehicle and the detector height is 1.45 m above ground. The detector is shielded by its dewar and the vehicle, but this shielding is mostly from directly beneath (the road surface). Radiation from a few meters distance from the road has fairly free passage to the detector through the car windows. Some additional shielding came from operating staff and other equipment (the PIC and Dynawatt units are positioned high up in the vehicle).

Our maximum driving speed during searching was 40 km/h in all areas but C7, where we drove the last part (south) according to speed regulations. On gravel roads the speed limit was actually set by the equipment, because microphonics in the crystal greatly increased with increasing speed and the useful speed was normally reduced to less than 30 km/h.

The spectrum acquisition time used during searching was 5 seconds. Our spectrometer is connected to a PC with Sampo software and during driving one person was dedicated to this computer screen at all times. The software displays a waterfall plot of the complete spectra (4096 channels), the total counts and the counts in three ROI areas (fig. 3 and 4). ^{137}Cs (661.7 keV) and ^{60}Co (1332.5 keV) where always in two of the ROI areas. The third area varied. In most search areas it was at ^{192}Ir (316.5 keV), but we also tried to keep it at very low energies (< 40keV) in an attempt to get an indicator for microphonic noise. This was not very successful. In an attempt to find also other nuclides the software did peak search and nuclide identification, and displayed the found peaks according to their peak significance in a separate window. The identified nuclides for each spectrum (usually none) where shown as a list on the computer screen. As nuclide library we used a "standard" library with the addition of some nuclides known to be used in medicine or the industry. All nuclides known to be imported, exported or sold in Finland during the year 2000 were marked with an "*" in the library to facilitate speedy decisions in the field.

When searching, the TSA scintillation detector mMCA-430 was used in search mode: when the measurement was started, the meter automatically counts background for 20 seconds. The meter gives an audible alarm, when the total count exceeds the background by 4 sigma levels

Our normal crew consists of three members. One person was concentrating on the SAMPO screen at all times. One person was obviously driving, and the third was responsible for navigating and "tactics". This person was also responsible for our handheld search instrument. In most areas during the exercise we had a fourth crewmember, who used the portable spectrometer.

The main difficulty in searching for sources was to screen out real sources from elevated background and detector noise (mainly microphonics and GSM-phones). Areas with elevated background where often large enough to be discriminated from point sources. In many cases visual inspection of the surroundings was a good tool for sorting out these areas. Rocky terrain, open cliffs or sand areas usually hold some uranium, which heightens the natural background.

The signal due to detector noise is not always easy to distinguish from a weak source with low energy or some collimation (fig. 3). Detector noise can always be ruled out by driving the same area (slowly) again, but this takes time and the rate of noise peaks in our detector was too high for us to be able to check every peak this way. So in many cases we made our decisions based on the TSA meter. If the total counts in the spectrometer suddenly rose by 50% there should have been an audible alarm also from the TSA meter if the rise was due to radiation. If the TSA meter did not detect anything we decided that the signal was probably due to detector noise.

Our aim was to scan as much of the road in each area as possible. The crew had no previous experience with measuring strong and partly shielded sources, so we wanted to take some time at the sources we found and describe them accurately (nuclide and strength). This lead to that we had to keep our driving speed as high as feasible, even at the risk of losing some weaker sources.

In the areas where we had flight data available we naturally tried to locate all sources that the aircrew had found.

Quite early in the exercise it became evident that the sources in the open areas (not prohibited to the public) were placed inside buildings. This lead us to drive more slowly near any buildings that looked like army storehouses, which was a very successful tactic.

Data analysis

After getting the first signal from a (suspected) source we used several methods for finding the exact location of the source.

- Visual inspection of the area

  This was often enough as many sources where clearly visible

- Determining the direction to the source using the gamma spectrometer in the car and led bricks to shield in different directions

  Moving lead bricks in front of the spectrometer and looking for the direction where the count rate was at a minimum was a fast and efficient way of locating the sources. With this method it was also possible to gain some information on the location of sources inside closed areas (buildings). It was also helpful in finding closely separated sources and discriminating between a ^{137}Cs source and an area with elevated fallout.

- Sending a crew member with handheld equipment

  In search mode the TSA mMCA instrument was very useful in locating sources within approx 50 m. When used in spectrum acquisition mode it was helpful in assessment of the shielding characteristics of the source i.e. helping to localise the maximum primary photon beam for more accurate analysis for HPGe-detectors.

After the exact location of the source was determined we tried to find the direction of minimal shielding and make our activity measurements from there either with the portable spectrometer or with the one in the car. In all cases we were able to find a direction where the primary peaks were prominent, so the nuclide identification was easy.

The source activity was first estimated from the gamma peak areas and corrected for distance and air attenuation. If several measurements were made from different locations the one, which yielded the highest activity was used and reported as apparent activity in the source identification report (SIR). To estimate the amount of shielding, the spectrum shape (height of peaks versus height of Compton continuum) was visually checked and the measured dose rate values where compared to dose rate values calculated assuming an unshielded source. The estimated source activity given in the SIR was not based on any exact calculation, but a true estimate derived from the above information.

The source location was taken from MapInfo, simply by estimating the distance and direction to the source from the present position of the vehicle taken from the GPS (non-differential) and shown on the map by the SAHTI dose-rate mapping software. The position was reported in RT-90 co-ordinates from the cursor location data shown in MapInfo.

During the exercise there was very limited time for post processing of data. After the exercise we have checked the data from areas where we went past sources without finding them. The post processing did not reveal any new sources.

Results

During the exercise we reported a total of 15 sources, with an addition of the two calibration sources in area C2 reported by many teams the total goes up to 17. All reported sources where correctly identified.

Source locations

Most sources were located correctly within a distance of 20 meters, which is enough for the purpose of this exercise. Some exceptions exist, especially the locations for sources 01:04 and 04:02 where further off. These sources where at places where you could not go by car, and our handheld GPS was in use in our support vehicle and the given maps where not detailed enough for locating the sources visually. The source 07:05 was off by approximately 35 meters too. Given that the position of the source given by the organisers is correct this can only be explained by a sustaining error in the GPS position.

Activity estimates

Our activity estimates were in most cases correct, although they seem to be a little bit low compared to the given values (fig. 1). The underestimation of the source 03:01 indicates the difficulty of estimating the activity of heavily shielded sources.

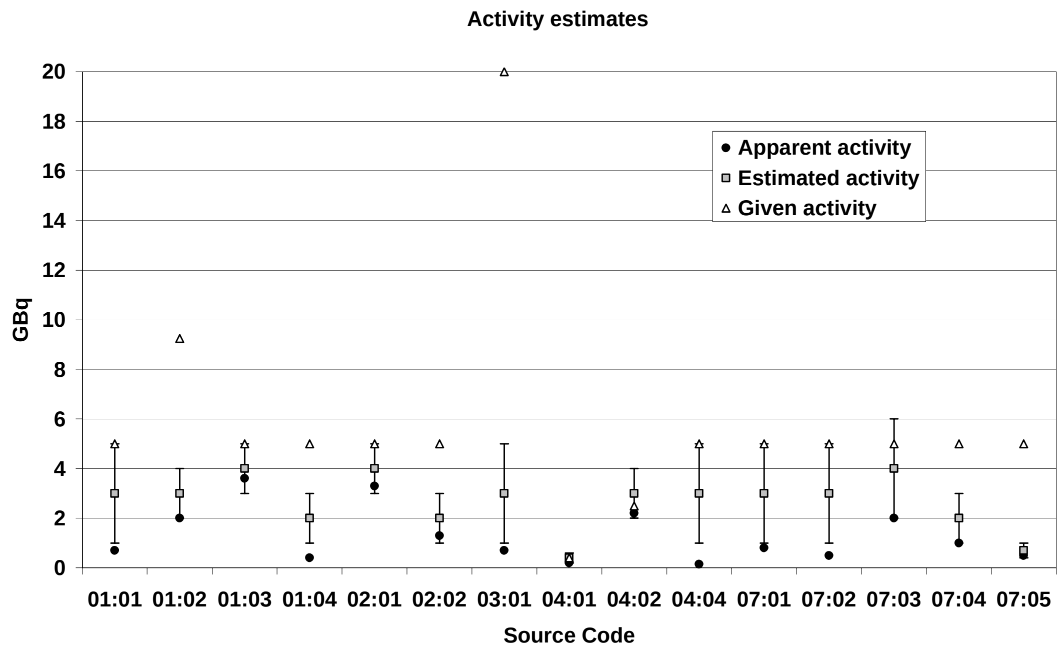

Fig. 1. *Estimated activity of the found sources compared to values given by the organizers. There seems to be some underestimation especially of the more heavily shielded sources.*

Area C1

In this area we had very good flight data available. The Finnish AGS team (FIA) had located all sources and it was an easy task to find them by car. We did not have a handheld GPS, so the location of the source 01:04 was reported according to the AGS data.

Area C2

The flight data for this area was not useful for us. The sources possibly located by the Finnish AGS team were in such locations that it was not possible to reach them by car or, within the given time frame, by foot. In this area there where some weak sources which we did not detect. In the post processing of the data we did not see any additional signal in the areas close to these sources. This in addition to the fact that no other team reported any of these sources during the exercise[1] leads us to the conclusion that the signals from these sources simply were too weak to be detected from a moving vehicle with the kind of instruments in use. (The ^{241}Am source at the gate was possibly reported as "source" by one team, but given the low activity and energy of the source, the possibility of detecting it would greatly depend on factors such as vehicle location on the road). The two big ^{60}Co sources in the bunkers where found and reported. As many other teams, we did not report the reference sources situated in this area.

Area C3

In this area we had good flight data available. In the area there was only one ^{60}Co source, which was very easy to find. Some confusion arose due to a military practice in the area, and accessibility of shooting areas, but we were able to scan practically all the roads.

Area C4

Because of fog problems for FIA we had no flight data available, so there where some sources normally detected by the air teams (04:03, 04:07) which we could not detect because of their great distance to roads.

The 1.9 GBq source (04:06) was located 100 metes from the road and from theoretical calculations one can derive that this source, if totally unshielded, should yield approximately 3 cps in the ^{137}Cs window, which would be above the detection level. However, in the specified location the actual ^{137}Cs count rate was below 0.5 cps, and the total counts well within normal variation, so the source was not detected, possibly due to some shielding.

The 0.4 GBq source in the red shed was the smallest detected source during the exercise. It was still very easy to detect, because of its proximity to the road (fig. 3).

The 2.5 GBq source in the "birdhouse" was the only source during this exercise that was close above the detection limit with our equipment. It was detected from the end of a small road from a distance of more than 100 meters. The maximum pulse rate in the ^{137}Cs window detected during the initial passage was 2 cps as compared to a normal background of 0 to 0.8 cps (fig. 4). This corresponds remarkably well with theory, as an unshielded ^{137}Cs source of 2.5 GBq at 125 meters distance would theoretically yield a count rate of 1.9 cps in the ^{137}Cs window. The detection was facilitated by the fact that the car was turned at the closest location to the sample, so we got several time slices with higher count-rates. The calculated dose-rate from the source at this distance is approximately 0.01 µSv/h and thus totally indistinguishable from background variation, which gives that spectrometric equipment was mandatory for this detection.

The source was identified as a point source and the direction to the source was determined using lead bricks, it was then located with the TSA meter and the activity estimates of the source were made using the portable spectroscopy system.

Of the two closely placed ^{60}Co-sources 04:04 and 04:05 we found only one. The other could clearly have been found with a little more careful examination of the area. The found source was easily identified, once a less shielded direction was found. On the shielded side of the source the shielding was so heavy that no primary photons were detected, even though the dose-rate was clearly elevated.

Area C7

The main difficulty in this area was to plan how to use our time. It was obviously impossible to scan the whole area. We were lucky in our decisions and managed to find all ^{60}Co sources, which were all very easy to find if you happened to drive on the right roads. The natural sources (^{226}Ra) were too small to be detected and distinguished from background, when driving by. No team reported any of them, and there was no detectable signal at the locations found in the post processing of the data.

All sources in this area were inside big military storehouses and we spent some time on each of them, trying to determine the approximate positions inside the buildings. We reported these positions in the form of sketches to REAC the next morning (fig. 5).

Conclusions

From an operational point of view, the exercise was a very positive experience for us and it was clearly demonstrated that the equipment and crew are able to successfully conduct this kind of missions. Some equipment improvements, which will be a part of our standard practice in the future, were made before the exercise. We gained valuable experience of overall equipment performance and the special demands that this kind of work puts on the operations and equipment that will be utilised in future designs (e.g. need of shielding from microphonics).

The exercise was, however, not very suitable for testing detection limits or gaining experience on specific instrument performance. There were very few sources dimensioned so that the signal when passing the source was close to the detection limit of contemporary CGS. This can clearly be seen from the fact that most sources where either detected by the majority of teams, or not detected at all. Also the other Finnish CGS team (FIK), which had no spectrometric equipment was able to find all the same sources, but one although the source 04:02 showed that spectrometric equipment in some conditions can be at least one magnitude more sensitive than dose-rate instruments.

References

1 https://secure.swerem.ssi.se/barents/portal.asp Web site open to participants after the end of the exercise.

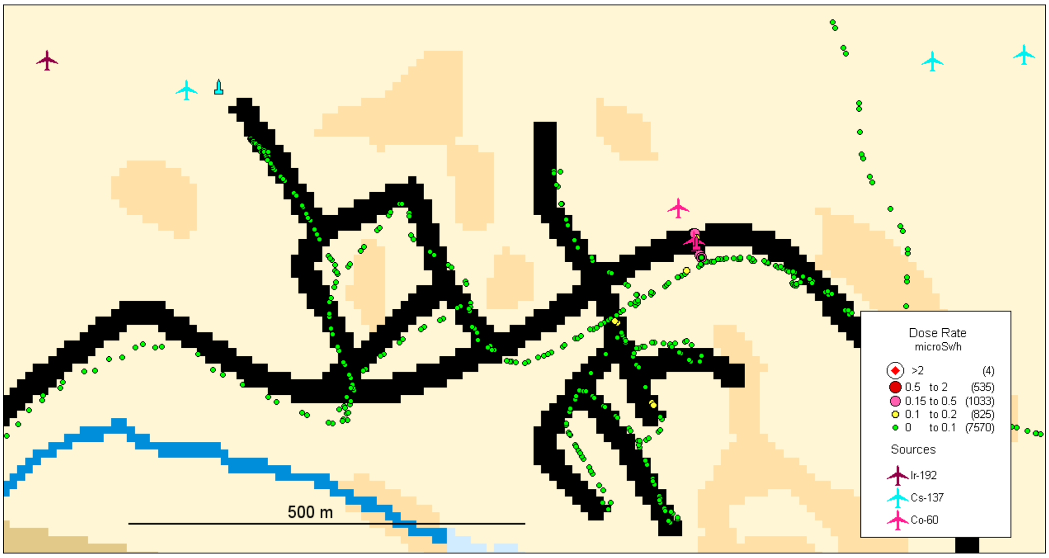

Fig. 2. *Detail of a part of area C4. The raster map fits reasonably well with GPS data (dots). One ^{137}Cs source (upper left corner) was found from the end of the road from a distance of approximately 100 m. The ^{137}Cs sources in the upper right corner and the ^{192}Ir source in the upper left corner was not found due to large distance to the road and lack of flight data. One of the two ^{60}Co sources in the middle right was found.*

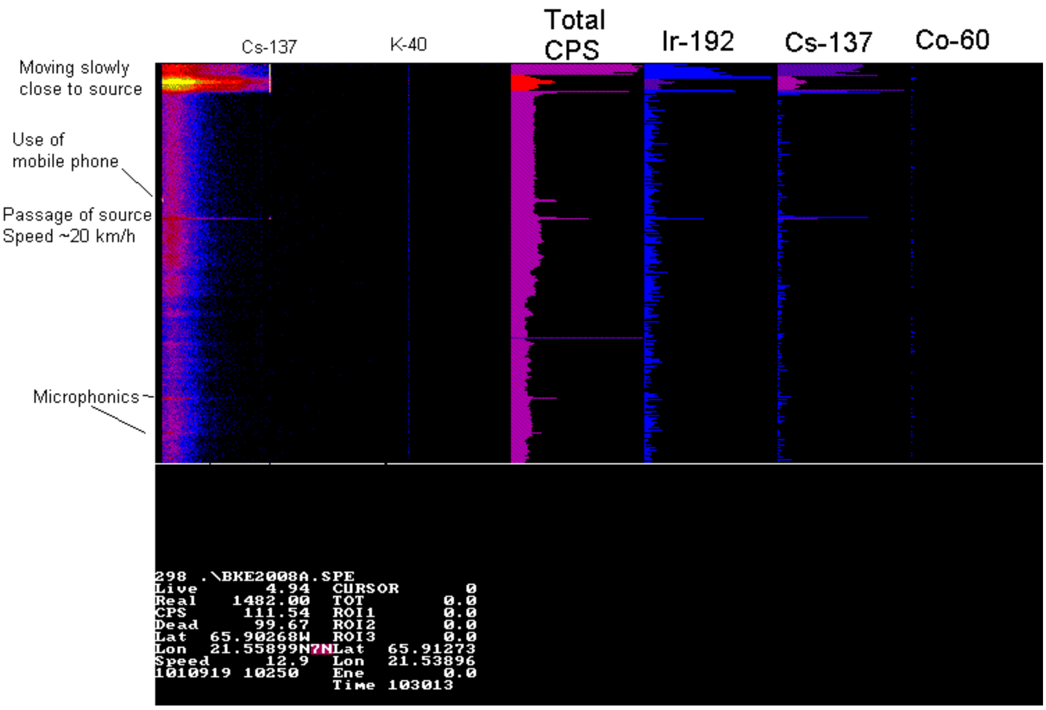

Fig. 3. *Waterfall plot of HPGe spectrum data (left). Energy increases to the right as time increases downwards. Higher count rates are shown with brighter colour. The right part of the diagram shows the count rates in three different ROI areas with histograms and colour changes. Data from source 04:01, which was the smallest source found during the exercise (^{137}Cs, 0.4 GBq). The source is very clear from a close distance (upper part), but is also easily detectable in all plot areas (waterfall, total cps, ROI) while driving past with normal search speed (middle). Use of mobile phone and microphonics give detectable signals in the total cps and waterfall areas.*

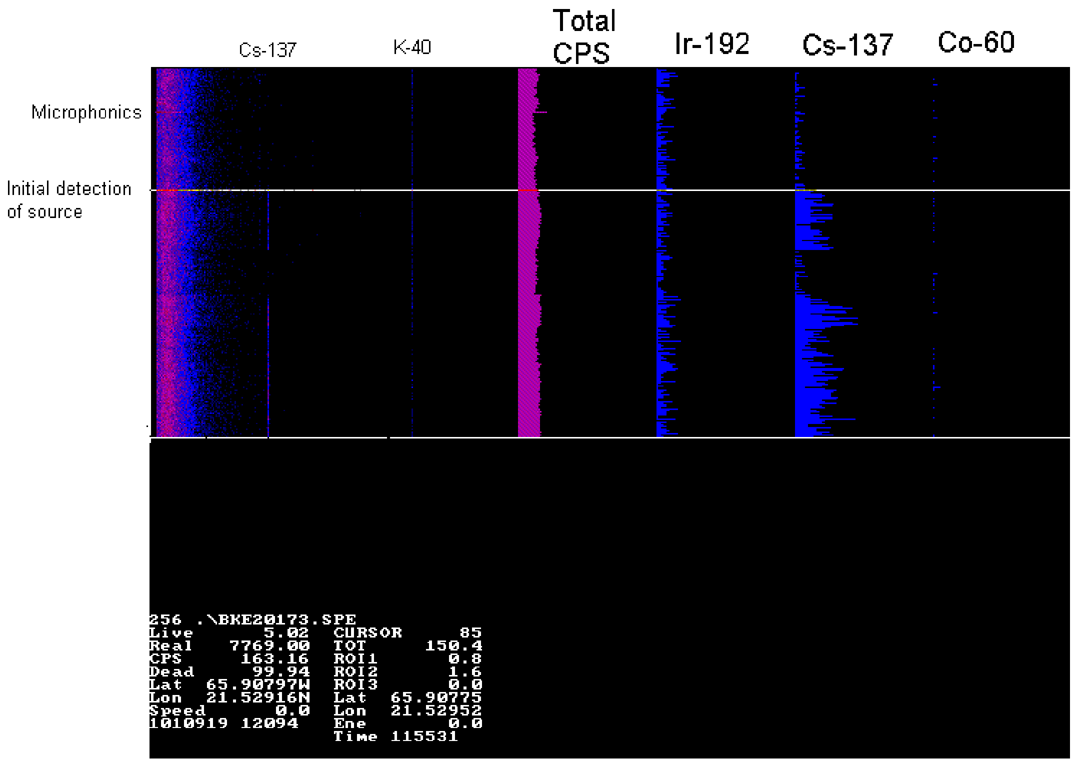

Fig. 4. *Data from source 04:02. The source was unshielded in this direction, and therefore detectable in the ^{137}Cs window. The signal is too weak to distinguish from background in the total count. In the waterfall plot the ^{137}Cs peak can be seen as a faint line. The distance to the source during collection of this data is ≥100 m.*

4. 7:5 0.7 ±0.3 GBq Co-60 source at 7331281, 1711660

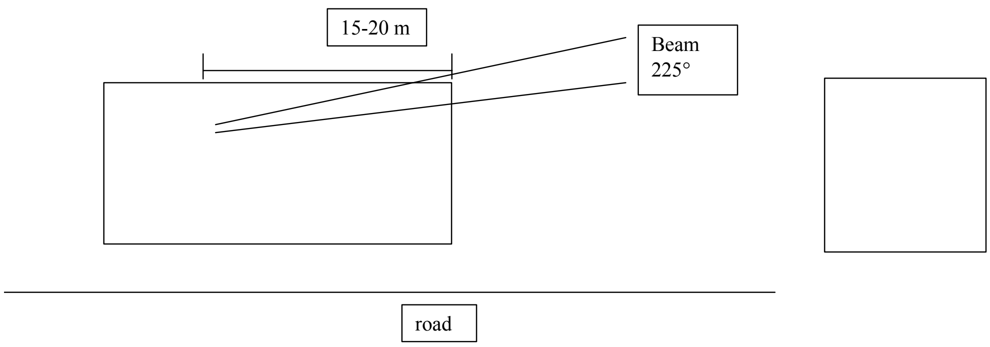

Fig. 5. *Example of a source sketch made during the exercise. The source was inside a big military storehouse. To estimate the location of the source inside the building we made collimated measurements from different directions.*

Latvia, team LVK

Latvian Team (LVK)

Anita Skujina, Andrejs Dreimanis, Latvian Radiation Safety Centre
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Equipment

Main equipment used for gamma search was mobile gamma spectrometer Exploranium GR-660 connected with Differential Geopositioning System (DGPS) mounted on the car Nissan Patrol. Measurements data were transferred afterwards to laptop Dell Latitude CPX and processed using Nucspec v.2.1 and Mapinfo software.

As supplementary hand held instruments serve GPS Garmin 45, portable gamma spectrometer Exploranium Minispec GR-130, dose rate meter RDS-120 and compass.

Methods

Exploranium GR-660 has 4 L NaI detector placed on the roof of the car at the height about 2.2 meters above ground level. For the spectrometer there has been set 512 channels measuring mode, each morning the device was calibrated using a standard Cs-137 source, then stabilized on natural Thorium. Spectrum has been recorded each 2 seconds, it means, that driving 30 km/h (typical speed used for gamma search) it represents average spectrum for each 16,7 m distance. Searching for the gamma source we used Show mode, where can see large number of last spectra. Each spectrum is shown as horizontal coloured pixel line, horizontal axis corresponds to the energy (channel number), colour – to the number of counts in channel. When some abnormalities or deviations in the colour picture had been noticed, the Spectrum window, rarely Chart window was switched on and checked if the changes have natural origin – rocks, granite, or are due to artificial source. When source had been found, the car was positioned so that to get as minimal as possible source shielding and optimal count rate, in order to obtain best spectral shape allowing to determine the radionuclide. Afterwards there has been determined source positioning coordinates using hand held GPS Garmin 45. Due to some confusion passing to RT90 coordinate system, DGPS data displayed on GPS window had wrong coordinate values, but nevertheless that in the data file there were recorded, with Nucspec 2.1 processed and in NKS format there were reported correct coordinate values.

To estimate the source activity the count rates and dose rates were measured in various directions and distances from the source, thereby searching for the direction where the source was less shielded. The directions respective to the source were estimated using compass.

Beside the spectrometer data, substantial role for gamma search played visual aspects: check of strange, unusual objects, such as left cars, trailers, etc. When these objects were not accessible by car, then hand held radiometer and spectrometer Exploranium Minispec GR-130 had been used. So there had been detected source 2:6 having well collimated narrow beam at the height 1.5 meters parallel to the ground. The spectrometer on the car cannot register this source, because the beam passed lower than detector.

Data analysis

Source apparent activity was estimated using expression:

$$A = 10^{-15} * D * R^2 / \Gamma,$$

where: A – Activity expressed in GBq;

D – Dose rate at the distance R from the source, µSv;

R – Distance to the source in meters;

Γ – Gamma constant characteristic for the given nuclide.

Substantial factor for correct activity evaluation was knowledge of the real distance from the source because due to high activity of the source there was not possible to step close to the source and often source was hidden inside the big storehouse. In such cases the actual distance to the source was calculated using two gamma rate measurements in the same direction along the beam and using expression:

$$R = (D_N + SQRT(D_N * D_D)) * d / (D_N – D_D),$$

where: R - Distance between the distal point and the source, in meters;

D_N, D_D – Dose rate at the nearest and the distal point, respectively, µSv;

d – Distance between both measurement points in meters.

When it deals with medium and low dose rates then it is very important to subtract the background dose rates before using the expression above. After search the measured spectra were processed using Nucspec 2.1 and results reported in NKS format to REAC.

Results

The results of Latvian gamma search cell LVK (and LVE) are summarized at the next table. For the sources not found or not identified background is set grey. In the column Estimated there have been put estimated apparent activities of sources and in column Δ - difference between the estimated and the actual coordinate. Latvian team LVK has found 18 gamma sources plus 2 sources found by LVE, it means 65% of all sources exposed for car born gamma search teams and 50% of sources exposed in area A5. In 4 cases there was not identified nuclide. By determining source coordinates the average deviation from the actual coordinate was some 12 meters. This corresponds to the accuracy of the hand held GPS Garmin 45. Source activity mainly was underestimated, because most of sources were more or less shielded and sometimes there was large uncertainties estimating the distance.

No.	Nuclide	GBq		Code/ Area	RT-90	Δ m	Placed
		Actual	**Estimated**				
1	**Co-60**	**5**	2.46	1:1/C1	1756005 7298134	10 29	In wooden cage in gravel pit, shielded upwards with concrete blocks
2	**I-131**	**9.25**	4.0	1:2/C1	1756005 7299224	20 11	In shed, collimated with lead bricks upwards and to the W
3	**Co-60**	**5**	0.44	1:3/C1	1755956 7299830	5 5	In wooden cage at the end of the road
4	**Co-60**	**5**	NF	1:4/C1	1756747 7300334	NF	In wooden cage on the south side of the closed road
5	**Co-60**	**5**	0.15	2:1/C2	1764029 7307246	-3 13	Inside the round concrete bunker
6	**Co-60**	**5**	0.05	2:2/C2	1764048 7307266	-7 14	Inside the concrete bunker, collimated obliquely upwards
7	**Mo-99**	**3.1**	NF	2:3/C2	1764844 7307031	NF	Inside tracked vehicle cart
8	**Mo-99**	**18**	NF	2:4/C2	1765350 7305451	NF	In the house on the attic
9	**Cs-137**	**3x0.5**	NF	2:5-1/C2	1763466 7306095	NF	Inside tracked vehicle cart, level guards, directed upwards
10	**Co-60**	**3x0.02**	NF	2:5-2/C2	1763466 7306095	NF	Inside tracked vehicle cart, level guards, directed SW
11	**Am-241**	**0.0004**	NE	2:6/C1/C2	1760526 7302595	-26 5	In cart, on the inside the hood, about 1.5 m above ground
12	**Co-60**	**4x5**	NE	3:1/C3	1766304 7316848	4 -27	In storehouse 36, side shielded with lots of concrete blocks
13	**Cs-137**	**0.4**	NE	4:1/C4	1760923 7321390	-1 6	In red shed, in lead container, side shielded
14	**Cs-137**	**2.5**	NE	4:2/C4	1760488 7323895	-14 -27	In "birdhouse". Shielded with a lead brick upwards
15	**Ir-192**	**13**	NF	4:3/C4	1760310 7323933	NF	Radiographic source in a tree
16	**Co-60**	**5**	NE	4:4/C4	1761137 7323702	23 -37	In concrete fire trench, covered with steel plate and sand
17	**Co-60**	**5**	NE	4:5/C4	1761117 7323744	3 5	In concrete fire trench, covered with steel plate and sand
18	**Cs-137**	**1.3**	NE	4:6/C4	1761442 7323932	-9 17	In tracked vehicle cart, shielded upwards with concrete blocks

19	**Cs-137**	**1.9**	NF	4:7/C4	1761559 7323941	NF	In tracked vehicle cart, side shielded with transport contain.
20	**Cs-137**	**2.6**	1.4	6:1/R1	1761020 7302427	-4 28	Reference source in tracked vehicle cart
21	**Co-60**	**5**	4.0	6:2/R1	1761670 7302884	20 12	Reference source in wooden cage
22	**Co-60**	**5**	0.5	7:1/ C7	1725376 7340248	-20 22	Storehouse 27, shielded to three sides
23	**Co-60**	**5**	1.0	7:2/ C7	1721169 7340769	-1 19	Storehouse 22, shielded to three sides
24	**Co-60**	**5**	0.125	7:3/ C7	1718957 7338223	32 18	Storehouse 51, collimated towards storehouse 52
25	**Co-60**	**5**	4.0	7:4/ C7	1718983 7338209	-7 5	Storehouse 51, collimated towards storehouse 52
26	**Co-60**	**5**	NF	7:5/ C7	1711648 7331315	NF	Storehouse 50, shielded with lead in different directions
27	**Ra-226**	**Nat**	NF	7:6/ C7	1721282 7340593	NF	Piece of rock from Kvarnån in wooden box at the roadside
28	**Ra-226**	**Nat**	NF	7:7/ C7	1718765 7337175	NF	Piece of rock from Kvarnån in wooden box at the roadside
29	**Ra-226**	**Nat**	NF	7:8/ C7	1712920 7318874	NF	Piece of rock from Kvarnån in wooden box at the roadside
LVE	**Cs-137**	**2.6**	NE	5:2/A5	1755733 7321627	83 37	In red shed no shielding
LVE	**Ir-192**	**46**	NE	5:5/A5	1756402 7324293	-11 0	Radiographic source below boulder

Conclusions

The obtained results by Latvian team and their analysis show that in searching and identification of sources the largest problems we encountered in following situations:

1) when the sources were rather strongly shielded – there were difficulties to identify the radionuclide in cases of relative large Compton effect;
2) when the nuclide was not included in the ROI;
3) in the cases where for the processing and analysis of the recorded data there were necessity for effective use of the NASVD method; we were insufficient skilled in the practical use of this method.

In the same time we found out that very important factor for efficient searching of a source is a choice of adequate searching strategy.

To sum up, Barents Rescue 2001 Gamma Search exercises were excellent opportunity to develop skills in search of unknown gamma sources using on car installed gamma spectrometer, share experience with colleagues from other countries and see our force or weakness and better reveal our mistakes. Great contribution in understanding each other was this opportunity to collaborate and report results in common NKS format.

It is reasonably such exercises repeat each two, three years. Gamma search exercises were perfect organised. Very worth was the possibility to pre-exercise some days before the real exercise and to get accustomed to the exercise conditions.

Acronyms

DEMA	Danish Emergency Management Agency;
GPS	Geopositioning System;
DGPS	Differential Geopositioning System;
LVK	Code assigned to the Latvian Gamma Search Cell;
NF	Not found;
NE	Not estimated;
NKS	Nordic Nuclear Safety Research;
REAC	Radiological Emergency Assessment Centre;
SRV	Swedish Rescue Services Agency

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H.K. Aage and U.Korsbech. Search for orphan sources using CGS equipment – a short handbook. Draft version. DTU.2001.

Acknowledgments

We very appreciate financial support from DEMA, SRV and NKS to the Baltic States. Thanks this support our participation in exercises was possible. Especially we appreciate technical support and consultations coming from our colleagues Kim Bargholz and Frank Andersen (DEMA).

Lithuania, team LTK

Results of LTK team within Gamma Search Cell of the *Barents Rescue 2001* Exercise

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Equipment

The main equipment used for searching sources was made by Exploranium firm. The portable spectrometer Exploranium GR-320 with a 4 L NaI (Tl) detector [1] mounted on the roof of the car was used for locating sources while the hand held spectrometer Exploranium GR-130 with a 70 mL NaI (Tl) detector [2] was used for both radionuclide identification and true activity estimation. The dose rate meter SRP-88H produced in Russia was used for exposure rate measurements at some locations, too. The crucial parameter in true activity determination is the source-to-detector distance. As the sources to be found were expected of very high activities the photographic camera with lens of focus 135 mm was used for distance measurements. The spectrometer Exploranium GR-320 combined with radiation surveillance system Exploranium GR-660 [3] provided 512 channel real-time gamma-ray spectra at every 2 seconds with the possibility to monitor at the color screen the all spectra collected during the last 5 minutes. In order to facilitate the identification of radionuclide by the help of this equipment the energy calibration was carried out using point sources of 152Eu (122 keV, 344 keV) and 137Cs (662 keV), and two lines of natural 40K (1461 keV) and 208Tl (2615 keV). The results of energy calibration are shown in Fig. 1.

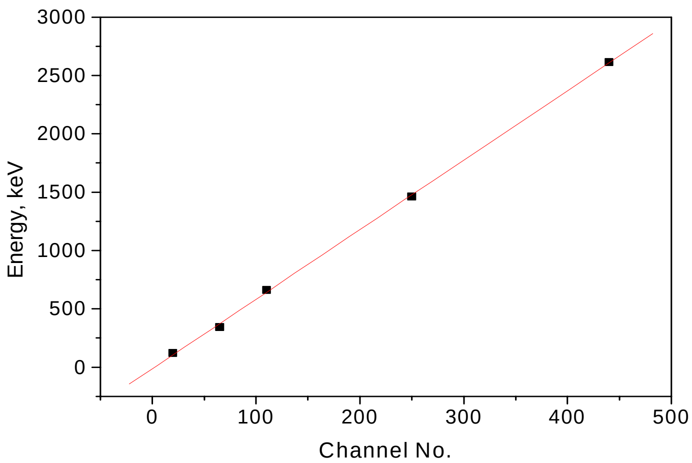

Fig. 1. Energy calibration for the *Exploranium GR-320*.

Radionuclide-specific efficiency calibration of the mobile spectrometer Exploranium GR-130 was done with regard to 137Cs using the reference source 6:1. The detector was positioned along the axis in the beam of gamma rays of maximum intensity at different distances from the source of known activity (2.6 GBq), and absolute efficiency has been calculated according to equation

$$\varepsilon_E = \frac{N_E}{A\eta} \qquad (1)$$

Here NE is full-energy peak counting rate expressed in counts per second, A is activity of radionuclide in the source, Bq, and η is emission probability of gamma-ray with energy E. Dependence of absolute counting efficiency on the distance from the source is shown in Fig. 2. The counting efficiency was fit to a power function with distance:

$$\varepsilon_{662} = 5 \cdot 10^{-6} r^{-1.7987} \qquad (2)$$

Here ***r*** is the distance in metres.

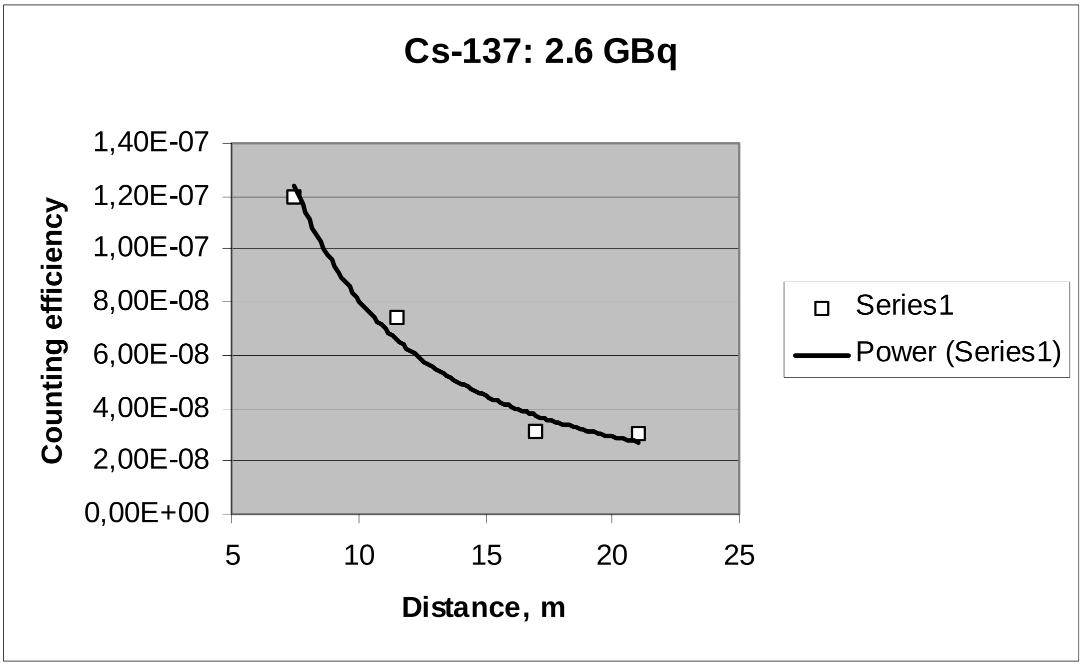

Fig. 2. Absolute counting efficiency versus distance for 662 keV energy, when using *Exploranium GR-130.*

Methods

The task was to find as many sources as possible and identify correctly the radionuclide type. Due to unknown shielding performance of each source the accurate quantitative analysis was of less importance. It was found during the pre-exercise on 16 September that the driving speed of approximately 20 km/h is sufficient to detect an event from collimated source (X:2-1, ^{137}Cs). High efficiency NaI(Tl) detector placed on the roof of the car at the height of 2.2 m from the earth surface was the main sensor indicating the presence of a source. This detector was sufficient to identify the radionuclide in many cases except the sources 1:2 and 2:2 when more detailed examination of the obtained spectra was needed by the help of hand held instrument *Exploranium GR-130*. The latter was used for ambient dose rate measurements, as well. The true activity has been estimated taking into account the maximum value of ambient dose rate due to radiation from the source at fixed distance. The source activity has been determined according to equation

$$A = \frac{D \cdot r^2}{\Gamma} \qquad (3)$$

Here A is the activity of the radionuclide in the source, Bq, D is the ambient dose rate, Sv/s, r is the distance from the source, m, and Γ is the gamma-constant for point source, m2 Sv Bq-1 s-1. Exposure rate can be used for point source activity determination, too. In this case, the different value for gamma-constant should be applied. The values of gamma-constants were taken from [4, 5]. In case of 137Cs, a true activity has been estimated by two methods: ambient dose rate conversion through the gamma-constants and counting rate at full-energy peak conversion through the absolute counting efficiency at fixed distance.

Data analysis

Radionuclide type was identified by the typical shape of gamma-spectrum (^{60}Co, ^{137}Cs) or by the position of the full-absorption energy peak of the most efficient gamma-ray emission (^{131}I). Some of the sources were hidden inside large storehouses, and the true distance to detector position was unknown in these cases. Together with varying shielding this was the main source of uncertainty in true activity estimations. The source 2:2 was shielded very heavy in all directions useful for car-borne gamma-ray spectrometry. Therefore, only scattered events could be seen in the spectrum. It looked as the spectrum of strong pure beta-emitter. This source was identified properly only after the detector was placed just above it. This geometry allowed obtaining full-energy absorption events and collecting respective gamma-spectrum.

Results

The results are summarized in table 1. The total number of sources found is 13. Reference and pre-exercise sources are not taken into account here. There is seen clear systematic underestimation of the true activity, except for both ^{137}Cs sources which were, probably, less shielded as compared to other sources. In case of ^{137}Cs, the true activity shown in table 1 is that calculated from ambient dose rate measurements and not from the full-energy peak area conversion. If the latter approach was used the true activity would be overestimated by the approximately three times of the actual one for both sources. It shows considerable difference in shielding extent between reference source 6:1 and both sources in question. Generally, the estimated true activity falls within 50% of the actual value. The sources 3:1, 7:1, 7:4 and, especially, 7:5 are exceptions. All of them are attributed to the storehouses. The larger deviation from the actual value in these cases can be explained by uncertain source-to-detector distance as well as by unknown variation in shielding performance.

Table 1. Results of source identification and activity determination.

Source code	Date	Radio-nuclide	Distance, m	Dose rate, μSv/h	Exposure, μR/h	Estimated true activity, GBq	Actual activity, GBq
1:1	01 09 19	^{60}Co	20	2.7	240	3.2±0.6	5
1:2	01 09 19	^{131}I	15	1.5	140	6.0±1.0	9.25 8.5*
1:3	01 09 19	^{60}Co	18	4.2	390	4.0±1.0	5
2:1	01 09 19	^{60}Co	7	14	1250	2.5±0.5	5
2:2	01 09 19	^{60}Co	3	70	n. m.	2.3±0.5	5
3:1	01 09 18	^{60}Co	10	3.4	415	1.1±0.2	4x5
4:1	01 09 18	^{137}Cs	10	0.52	n. m.	0.65±0.1	0.4
4:2	01 09 18	^{137}Cs	15	1.35	n. m.	3.4±0.6	2.5
4:4	01 09 18	^{60}Co	10	6.2	n. m.	2.5±0.5	5
4:5	01 09 18	^{60}Co	10	6.1	n. m.	2.5±0.5	5
7:1	01 09 17	^{60}Co	10	2.5	n. m.	1.0±0.3	5
7:4	01 09 17	^{60}Co	7	8.5	640	1.6±0.5	5
7:5	01 09 17	^{60}Co	3	0.9	n. m.	0.026±0.006	5

- * Decay -corrected value for 19 September assuming that the activity of 9.25 GBq was valid on 18 September.
- n. m. Not measured

Conclusions

Using car-borne gamma-ray spectrometry there were 13 "orphan sources" found during the exercise. The radionuclide type was identified and a true activity of each source was estimated. It was very useful experience for the LTK team. The equipment was calibrated and tested in field conditions. The results obtained were fairly good: all sources found were identified correctly, true activity estimated with sufficient accuracy. However, some sources were missed. The reasons for that could be listed as follows:

1. Driving speed was sometimes too high
2. Not all suspiciously-looking targets were checked carefully
3. Demanding exercise and limited time did not allow to check absolutely all roads

Acknowledgement

The authors express their appreciation to the Danish team for the technical assistance during the exercise and, especially, for the maintenance of the detector.

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Norway, team NOK

Team NOK

Mark A. Smethurst, John O. Mogaard, Eirik Mauring, Janusz Koziel, Ola Kihle

Equipment

Vehicle

The measuring equipment for team NOK is mounted in a four-wheel-drive Toyota Hiace van (Fig. 1; Smethurst 2000). The van has a crew of two, a driver and an instrument operator, both seated in the front of the vehicle.

Figure 1. The measuring system used by team NOK of the Geological Survey of Norway. Note that the 16.7 litre NaI detector behind the side door can be rotated to present a larger cross-sectional area to the left and right sides of the road.

Fixed Instrument

The principal measuring instrument for mobile source detection is an Exploranium GR-820 256-channel gamma ray spectrometer utilizing an Exploranium GPX-1024 16.7 litre NaI detector. Counting time is usually set to one second but this can be increased to 5 seconds.

The detector is supported a few centimetres beneath the roof of the van on a steel frame. The centre of the detector is at a height of 1.5 m. The frame permits the rotation of the detector about an axis aligned with the direction of travel of the vehicle. The detector can be rotated and fixed so that its largest surface faces directly out to the side, maximising the sensitivity of the instrument to near-horizontal radiation from sources situated on or near the ground to either side of the vehicle.

Hand-held instrument

An Automess 6150 AD6 dose rate meter is used to monitor dose rates in the vehicle for the protection of the crew. The instrument is also used outside the vehicle for determining the precise locations of radioactive sources and the doses associated with them.

Navigation

The vehicle's location is determined once every second using an Ashtech G12 GPS receiver linked to a dedicated PC. The navigation system is able to deliver most kinds of projected coordinates in real-time – including the Swedish RT90 coordinate system used in the Barents Rescue exercise.

If the Automess dose rate meter is used at some distance from the vehicle, a position of the dose measurement can be obtained from a hand-held Garmin GPS 12 XL GPS navigation device.

Real-time data processing, data display and data logging

A laptop computer situated on the dashboard of the vehicle acquires data from the gamma ray spectrometer and navigation system, processes the data, displays the data in various forms, and records the data on disk in binary (full spectrum) and ASCII text forms (NKS format).

Methods

Strategy

The NOK team, from the Geological Survey of Norway, exercised both a field measuring crew, present in Boden, and support personnel at the Geological Survey of Norway headquarters in Trondheim. The field team reported to the Barents Rescue Radiation Emergency Assessment Centre (REAC) as instructed, and shortly afterwards sent full spectrum data to Trondheim. The team in Trondheim archived the data, produced large-format maps of various kinds, and produced an independent interpretation of the data. The Trondheim interpretation of sources was then sent back to the field crew in Boden together with a selection of illustrations and map images (Fig. 2).

The field strategy for team NOK was to measure along all roads within each search area in the time allocated by the Gamma Search Cell leadership. Importance was placed on scanning the entire search area for strong and potentially hazardous sources at the risk of bypassing weak sources. With a large detector, measuring once a second, we set a maximum speed of 50 km/h. In practice we drove between 30 and 50 km/h and still covered most of the roads in each search area.

The search for sources was founded solely on data from the principal measuring instrument, the gamma ray spectrometer. Only when that instrument gave indication of a source did we stop the vehicle and investigate the surrounding area on foot. We did not stop and check objects at or near the roadside simply because they were there.

It was also decided that we should report a single dose rate and cps (counts per second) measurement for each source found, even though several measurements of each source were made, so that more time could be spent covering the search area.

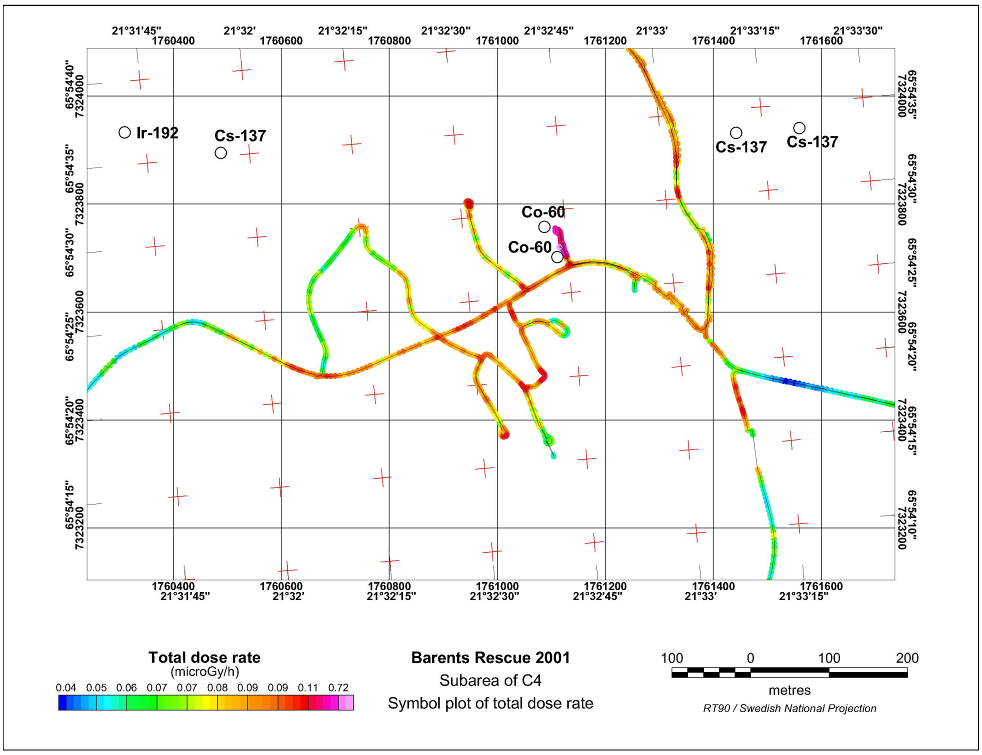

Figure 2. Example map of dose rates measured along tracks in the middle of area C4, 18/09/2001. Note that a non-linear colour scale has been used.

Surveying parameters

In most situations driving speed was set to between 30 and 50 km/h. The NaI detector was turned on its side in order to present as large a cross-sectional area as possible to the left and right sides of the road.

Data analysis

All data processing is done in real-time. Conventional window stripping is performed to provide an indication of the amounts of naturally occurring K-40, daughters of U-238, and daughters of Th-232 in the surrounding natural environment (IAEA 1991). These values and the ‘cosmic window' value (spectrum channel 255) are used to scale unit gamma ray spectra for K-40, U-238, Th-232 and cosmic radiation before they are summed to yield a model of the natural spectrum. The model spectrum is then subtracted from the measured spectrum to produce a residual or ‘man-made’ spectrum. If the model spectrum is a close fit to the observed spectrum, the ‘man-made’ spectrum is virtually zero (Fig. 3). If there is an exotic radionuclide within detection range, the ‘man-made’ spectrum resembles the gamma ray spectrum of the exotic nuclide (Fig. 4). Dose rate (air kerma rate) is determined from the sum of energy-weighted channel count rates (Bargholz 1996, Bargholz & Korsbech 1997) for the observed spectrum (total dose), model spectrum (natural dose) and ‘man-made’ spectrum (dose from source). The integrity of the natural model can break down when a photo-peak from an exotic source impinges on one of the energy windows used in the stripping process. The 1330 keV photo-peak for Co-60 does this. Even in this situation, where the spectra for natural and man-made sources are not properly separated, the deviation from natural behaviour is large enough to be quite obvious and the source is found.

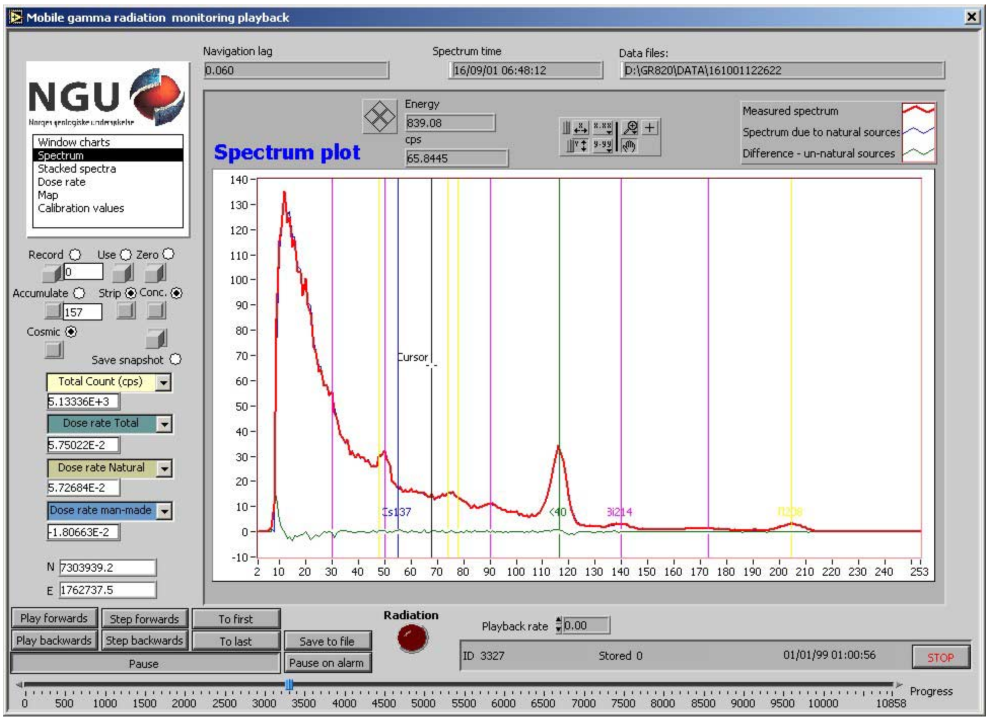

Figure 3. Spectrum plot from area C2 16/09/2001 (counts per second versus spectral channel) showing almost exact agreement between the observed (red) and model spectrum (blue). The residual or 'man-made' spectrum is in green. Dose rates are in μGy/h and position in RT90.

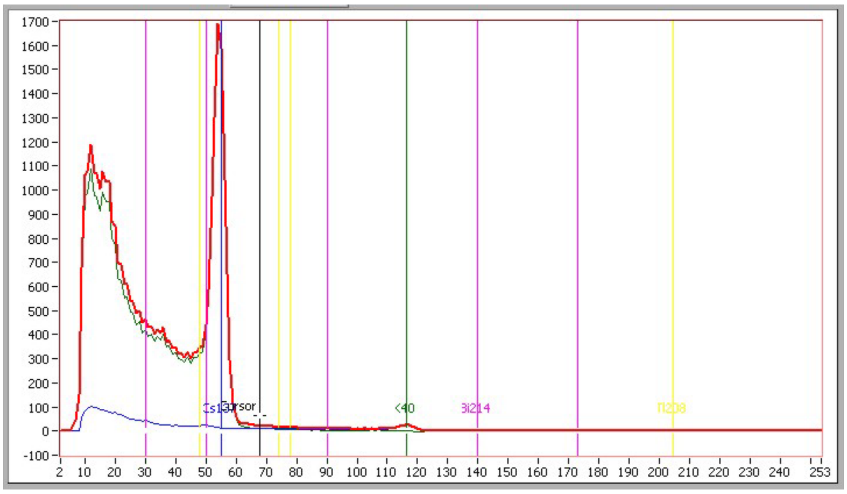

Figure 4. Spectrum plot near the Cs-137 source 6:1 in test area R2. The 'man-made' spectrum (green) contains the photo-peak for Cs-137 at 662 keV and dominates over the model for natural radiation sources (blue).

A display of successive ‘man-made’ spectra in a ‘rainbow-plot’ (Fig. 5) linked with a complex alarm is the principal tool for source detection. Constantly varying and distracting natural spectra are virtually absent in this display, whereas significant deviations from normal, natural, behaviour are enhanced. Nuclide identifications are based on visual examination of spectral shapes.

In most situations during the Barents Rescue exercise visual contact was made with either the sources themselves or the structures that enclosed them. In these cases the location of the source was rapidly determined through direct observation from the vehicle and dose rate measurements made on foot. When practical to do so, the NOK team performed a controlled drive-by of the source to produce a simple source profile shape that could then be used to estimate distance to the source. Also estimates of source activity were made based on an adaptation of equation 9.1 given by IAEA (1991).

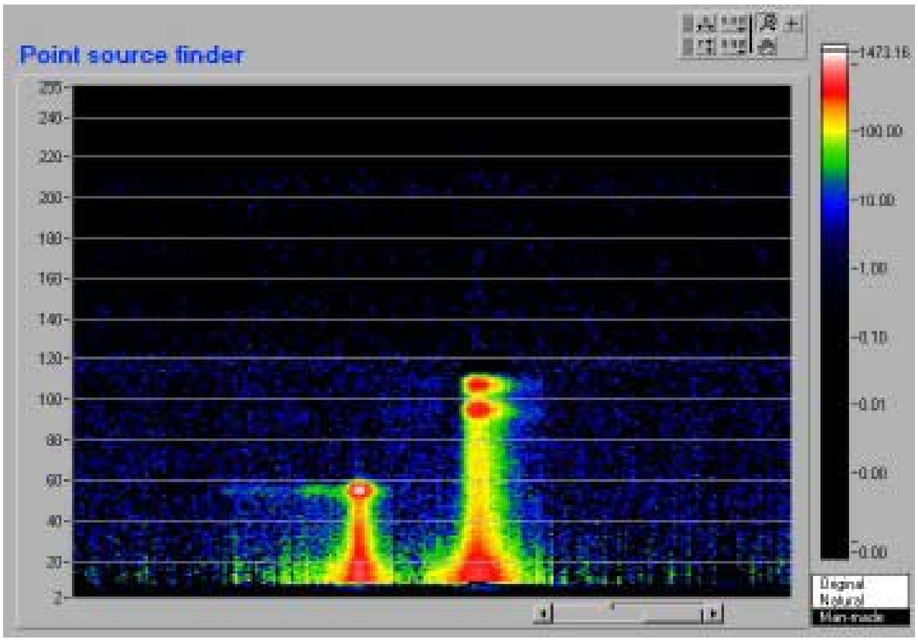

Figure 5. 'Rainbow plot' of a drive by of sources R1:1 (Cs-137, left) and R1:2 (Co-60, right) at the helicopter airfield in Boden. This display form, consisting only of the difference spectrum ('man-made' spectrum), was heavily used in the exercise. The plot consists of vertical coloured strips, each representing one spectrum. Each new measurement appears as a vertical strip at the right of the screen and the previous measurements scroll to the left. For each strip the vertical axis represents spectral channel while colour is used to indicate counts per second in each channel. Warm colours denote high values.

Results

Source identifications were reported to REAC by mobile telephone. Relevant processed data, including source position in RT90, could be read directly from the computer screen in the car in real-time. There were only two or three occasions when contact with REAC could not be established within a few minutes of source detection.

Finished processed measurements were stored in NKS files in real time. Each day’s track data, amounting to some 30,000 measurements made over 9 hours, were delivered to the REAC shortly after returning to the Exercise Area. Measurement data were checked in the vehicle during the half-hour journey from the search area back to the Exercise Area. This check included loading the NKS file into a map-making package, Geosoft Oasis Montaj, and making a map of the day’s data. The NKS files and example maps were delivered to REAC before 6 pm.

Copies of the data were sent to Trondheim where an independent search for sources took place. Each day’s data took less than three hours to analyse (one third of the real data acquisition time), including the production of various maps of the data. The Trondheim team recognised all of the sources reported by the NOK field team in Boden and further refined the interpretation of the data.

The tables below summarise the performance of the NOK team in the various parts of the Barents Rescue exercise for car-borne measuring systems. The tables list all the sources present in the search areas, and indicate which of these were found by the NOK team. If a source was not found, a reason is given in the table. Overall, the NOK team made 16 positive source identifications, reported 2 small areas with Chernobyl fallout within search area C3, and made 2 false source identifications. Two additional sources were identified in the data during post processing. Otherwise, six sources (or source pairs) were passed without detection (only two of these were 'strong' sources), and 9 were not visited by NOK.

Explanation of tables

The result tables include official information on the sources on the left and the results of the NOK team on the right. Positions for the sources are in Swedish RT90. The difference between the official position and the position reported by NOK is given under the heading 'Diff.'. We are uncertain of the relative accuracies of the two estimates of position.

The tables include selected measurements of the sources. Measurement type (a) is derived from the gamma ray spectrometer (detector height 1.5 m). The measurement is in counts per second (e.g. 31700), measured at a given distance from the source (e.g. 20 m) in a given direction from the source (e.g. SW). Measurement type (b) is air kerma rate (µGy/h), also derived from the gamma ray spectrometer, for the same position relative to the source. Measurement type (c) is dose rate (µSv/h) obtained from the Automess dose rate meter for a position close to that of (a) and (b).

Pre-exercise, Sunday 16/09/2001 search area C2
Approximate percentage of roads driven: 98%

Official information on source				Result from team NOK Source found; False source; Chernobyl fallout; Found in post-processing; Passed by but not found; ☒ Source not visited				
Nuclide	**GBq**	**Code**	**Posn.**	**Nuclide**	**Posn.**	**Diff.**	**Measurement**	**Result**
Cs-137	**2.6**	6:1	1761020 7302427	**Cs-137**	1761020 7302427	0 m	a. 31700 @ 20 m SW b. 0.47 c. 0.45	Positive identification in real-time, Exact knowledge of source location (military trailer). Investigated on foot. Photo-peak at 662 keV.
Co-60	**5**	6:2	1761670 7302884	**Co-60**	1761670 7302890	6 m	a. 20300 @ 47 m SE b. 0.40 c. 0.45	Positive identification in real-time, Exact knowledge of source location (chaotic wood stack). photo-peaks at 1170 and 1330 keV.
Cs-137	**1.9**	X:1	1762946 7303659	**Cs-137**	1762928 7303669	20 m	a. 17010 @ 2 m N b. 0.19 c. 0.26	Positive identification in real-time, Exact knowledge of source location (civilian trailer). Photo-peak at 662 keV.
Cs-137	**0.5**	X:2-1	1764308 7308519					Driven past source – no trace of the source in the data set.
Co-60	**0.02**	X:2-1	1764308 7308519					Driven past source – no trace of the source in the data set.
Cs-137	**2x0.5**	X:3	1764698 7306720	**X**				Short side road not driven.
Co-60	**2x0.02**	X:4	1764300 7306424	**X**				Short side road not driven.
Cs-137 **Cs-137** **Cs-137** **Co-60** **Co-60** **Ba-133**	**1.3** **1.9** **0.4** **0.1** **0.1** **0.004**	X:5	1763856 7305822	**Cs-137**				Post-processing: Cs-137 source/s observed in two successive spectra measured a few metres from the source/s. The Cs-137 source/s were only within detection range for 2 seconds and were therefore overlooked by the measuring team. Team NOK did not stop unless the primary measuring instrument gave indication of a possible source. No source was noticed and therefore we did not stop to investigate on foot.

Barents Rescue exercise, Monday 17/09/2001 search area C7
Approximate percentage of roads driven: 80%

Official information on source				Result from team NOK Source found; False source; Chernobyl fallout; Found in post-processing; Passed by but not found; ☒ Source not visited				
Nuclide	**GBq**	**Code**	**Posn.**	**Nuclide**	**Posn.**	**Diff.**	**Measurement**	**Result**
Co-60	**5**	7:1	1725376 7340248	**Co-60**	1725380 7340240	9 m	a. 39157 @ 20 m E b. 0.88 c. 1.00	Positive identification in real-time, Exact knowledge of source location (military warehouse). Investigated on foot. Shielded source – strong 'beam' through door. Photo-peaks at 1170 and 1330 keV.
Co-60	**5**	7:2	1721169 7340769	**Co-60**	1721159 7340790	23 m	a. 56200 @ 20 m N b. 1.12 c. 1.89	Positive identification in real-time, Exact knowledge of source location (military warehouse). Investigated on foot. Spectral peaks at 1170 and 1330 keV.
Co-60	**5**	7:3	1718957 7338223	**Co-60**	1718945 7338220	12 m	a. 160000 50m NNW b. 2.60 c. 11.00	Positive identification in real-time, Exact knowledge of source location (military warehouse). Investigated on foot. Photo-peaks at 1170 and 1330 keV.
Co-60	**5**	7:4	1718983 7338209	**Co-60**				This and the above source were located in the same military ware-house. Team NOK interpreted the two sources as one single source.
Co-60	**5**	7:5	1711648 7331315	Un-identified	1711641 7331309	9 m	a. 6210 @ 3 m N b. 0.40 c. ?	Source found in real-time, Exact knowledge of source location (military warehouse). Investigated on foot. Shielding around source, no characteristic photo-peaks observed – isotope not identified.
Ra-226	**Nat**	7:6	1721282 7340593					Driven past source – no trace of the source in the data set.
Ra-226	**Nat**	7:7	1718765 7337175					Driven past source – no trace of the source in the data set.
Ra-226	**Nat**	7:8	1712920 7318874	**Ra-226**				Post-processing: Ra-226 source observed.
Reported				Low energy gamma	1741435 7295615			Suspicious low energy gamma radiation – not explained by live modelling of natural radiation sources. Reported to REAC as "Possible distant source"
Reported				Low energy gamma	1717881 7336290			Suspicious low energy gamma radiation – not explained by live modelling of natural radiation sources. Reported to REAC as "Possible distant source"

Barents Rescue exercise, Tuesday 18/09/2001 search areas C3 (morning) and C4 (afternoon)
Team NOK accompanied by Norwegian civil defence force with dose rate meters.
Approximate percentage of roads driven: 90%

Official information on source				**Result from team NOK** Source found; False source; Chernobyl fallout; Found in post-processing; Passed by but not found; ☒ Source not visited				
Nuclide	**GBq**	**Code**	**Posn.**	**Nuclide**	**Posn.**	**Diff.**	**Measurement**	**Result**
Co-60	4x5	3:1	1766304 7316848	Co-60	1766288 7316863	21 m	a. 175000 @ 6 m N b. 1.83 c. 1.00	Positive identification in real-time, exact knowledge of source location (military warehouse). Investigated on foot. Shielded source – strong 'beam' through door. Photo-peaks at 1170 and 1330 keV. Heavily shielded – characteristic photo-peaks absent from most vantage points.
Cs-137	0.4	4:1	1760923 7321390	Cs-137	1760897 7321397	27 m	a. 51550 @ 8 m S b. 0.81 c. 0.50	Positive identification in real-time, exact knowledge of source location (red wooden shed). Investigated on foot. Photo-peak at 662 keV.
Cs-137	2.5	4:2	1760488 7323895	X				Did not drive past this source (narrow track deep inside shooting range).
Ir-192	13	4:3	1760310 7323933	X				Did not drive past this source (narrow track deep inside shooting range).
Co-60	5	4:4	1761137 7323702	Co-60	1761122 7323712	18 m	a. 87570 @ 12 m N b. 2.37 c. 0.40	Positive identification in real-time, exact knowledge of source location (concrete bunker, open upwards, with metal plate weighed down by stones over the opening). Photo-peaks at 1170 and 1330 keV. Complex shielding. Investigated on foot.
Co-60	5	4:5	1761117 7323744	Un-identified	1761102 7323749	16 m	a. 27420 @ 7 m E b. 0.32 c. 0.20	Source found in real-time, exact knowledge of source location (concrete bunker, close to source above). Complex shielding, no characteristic photo-peaks observed – isotope not identified. Investigated on foot.
Cs-137	1.3	4:6	1761442 7323932	X				Drove close to but not past this source.
Cs-137	1.9	4:7	1761559 7323941	X				Drove close to but not past this source.
Fallout			C3	Chernobyl fallout Cs-137	1766257 7318837			Traces of Chernobyl fallout in the neglected lawns between abandoned residential buildings at road junction.
Fallout			C3	Chernobyl fallout Cs-137	1767383 7315342			Traces of Chernobyl fallout around two run-down wooden warehouses.

Barents Rescue exercise, Wednesday 19/09/2001 search areas C1 (morning) and C2 (afternoon)
Team NOK accompanied by Norwegian civil defence force with dose rate meters (morning).
Approximate percentage of roads driven: 95%

Official information on source				Result from team NOK Source found; False source; Chernobyl fallout; Found in post-processing; Passed by but not found; ☒ Source not visited				
Nuclide	**GBq**	**Code**	**Posn.**	**Nuclide**	**Posn.**	**Diff.**	**Measurement**	**Result**
Co-60	**5**	1:1	1756005 7298134	Co-60	1755997 7298125	12 m	a. 131900 @ 20 m SW b. 1.35 c. 0.5	Positive identification in real-time, exact knowledge of source location (in green box under camouflage net). Investigated on foot. Photo-peaks at 1170 and 1330 keV.
I-131	**9.25**	1:2	1756005 7299224	Un-identified	1755981 7299234	26 m	a. 17320 @ 2 m SW b. 1.45 c. 20.00	Source found in real-time, exact knowledge of source location (in raised wooden shed – source visible from outside). Shielded source – strong 'beam' towards the road. Clear photo-peak at 364 keV plus others.
Co-60	**5**	1:3	1755956 7299830	**X**				Did not drive past this source. Shortest distance from source to road network: 450 m.
Co-60	**5**	1:4	1756747 7300334	**X**				Did not drive past this source. Shortest distance from source to road network: 525 m.
Co-60	**5**	2:1	1764029 7307246	Un-identified	1764025 7307254	9 m	a. 94370 @ 5 m E b. 1.04 c. 0.8	Source found in real-time, exact knowledge of source location (inside a concrete bunker – wood covering the opening). No characteristic photo peaks.
Co-60	**5**	2:2	1764048 7307266	**Co-60**	1764041 7307275	11 m	a. 149420 @ 6 m SE b. 1.65 c. 1.2	Positive identification in real-time, exact knowledge of source location (inside a concrete bunker – wood covering the opening). Investigated on foot. Photo-peaks at 1170 and 1330 keV.
Mo-99	**3.1**	2:3	1764844 7307031					Driven past source – no trace of the source in the data set.
Mo-99	**18**	2:4	1765350 7305451	**X**				Did not drive past this source.
Cs-137	**3x0.5**	2:5-1	1763466 7306095					Driven past source – no trace of the source in the data set.
Co-60	**3x0.02**	2:5-2	1763466 7306095					Driven past source – no trace of the source in the data set.
Am-241	**0.0004**	2:6	1760526 7302595					Driven past source – no trace of the source in the data set.

Conclusions

The measuring system employed by the NOK team proved to be reliable. 140,000 measurements were made in Boden over 8 days without technical failure. We feel that the source search strategy worked well and are satisfied that comparatively few strong sources were overlooked in the short time allocated for searching. We are also pleased that the support team in Trondheim were able to reproduce the results of the on-site team. The Barents Rescue exercise was a positive and learning experience for the NOK team members and we now feel better prepared for emergency measurements of this kind.

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Norway, team NOL

Norwegian Team (NOL)

Mark Dowdall, Norwegian Radiation Protection Authority
Tor Christian Berg, Norwegian Institute for Air Research

Equipment

The vehicle used by the NOL team was a standard rental van of the Hiace type. Mounted in the rear of the van was a 16 l NaI detector (4 x 4 l) manufactured by Exploranium Ltd. (Exploranium model 1024) mounted on a custom built adjustable, shock absorbing, rack system (NILU) which supported the detector at a height of approximately 1 – 1.5 meters from the surface of the road. The rack was designed to allow the detector to be tilted towards the roadside in a configuration that allowed for the maximum signal to be accumulated from the right hand side of the van. The door was closed during normal operation to reduce the ingress of contaminant dust into the van interior. The detector was connected to a Canberra Inspector MCA (model 1200), the output from which was fed to a laptop personal computer. The laptop computer was custom configured to accept data simultaneously from the MCA and from a roof mounted GPS unit. The software used was a custom program developed by the Geological Survey of Norway (NGU) and slightly modified by the NRPA. The program was developed in LabVIEW from the National Instruments Corporation. This program was originally developed for radiometric exploration purposes and the layout and functions of the system reflect that intention. The software allows for continuous observation of a gamma ray spectrum, counts at various regions of the spectrum and a measure of the ambient dose equivalent rate. A more detailed description of the program may be found in [1]. The team was also equipped with a range of portable dose meters.

Methods

The NOL strategy involved traversing each road in the search areas from both directions. A background measurement, consisting of approximately 40 readings, was taken upon entering each search area. This background was then subtracted from all subsequent readings. The car speed was maintained at approximately 30 km per hour. Readings were taken every two seconds. Elevated radioactivity was determined by the appearance of the acquired spectrum, the numbers of counts in specific spectral “windows” corresponding to the emission energies of a number of nuclides and the elevation of the dose rate above a certain threshold value. Areas of suspected elevated activity were noted and were then returned to for a more detailed examination. This involved acquiring a spectrum at various distances and orientations to the suspected source for identification purposes and surveys on foot with portable dose meters in order to ascertain the orientation, shielding and collimation of the source.

Data analysis

Sources were identified on the basis of their characteristic emissions at certain energies. These were identified manually from the gamma spectra obtained. Activity calculations were based on the dose rate and the distance from the source using certain factors for different nuclides.

Results

Technical problems during the early stages of the exercise prevented the searching of area C7. The team located 1 source in C1, 2 in C2, the single source in C3 and 2 sources in C4. Of these, 4 sources were correctly identified. In common with the majority of teams, activity estimates were poor. This may possibly be attributed to the positioning and collimation of the sources. It proved extremely difficult to estimate distances from sources in many cases as the sources were often placed at unknown locations in large buildings and this made estimation of distance from the source very difficult to judge. Secondly, the level of shielding on any source was unknown. Identification of sources was largely dependant on the isotope involved. Sources consisting of Cs-137 and Co-60 were relatively easy to identify although this was not always true where the sources were placed in close juxtaposition or where collimation prevented positioning of the equipment in an ideal position. Positioning and collimation of some sources hampered location, such as, for example, when the source was collimated to point upwards or away from the road.

Conclusions

Given the level of technical problems encountered, the team were satisfied with their performance and that of the equipment used. The exercise did highlight the need for more hand-held equipment, particularly spectrometers and the need for equipment providing better energy resolution than that provided by NaI was also apparent. Methods of calculating activity may require further investigation. The team is currently investigating improvement of the software in relation to optimisation for the detection and identification of anthropogenic sources and investigating methods for the improved estimation of dose rate over larger distances.

References

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Poland, team PLK

Polish Team (PLK)

Krzysztof ISAJENKO, Pawel LIPIŃSKI

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Equipment

The Central Laboratory for Radiological Protection uses 4 liter NaI(Tl) detector placed on the roof of the TOYOTA Land Cruiser vehicle. The detector is connected to Exploranium GR-660 system which consists of GR-320 portable spectrometer, differential Global Positioning System, on-board computer running 660Rover software for the visualization and simple analysis of the data. The Polish team uses hand-held MiniSpec GR-130 spectrometer/survey meter for performing of the measurements while out of the car.

Figure 1. Polish Mobile System

Methods

The 4-liter NaI detector is placed at the right side of the car, on the roof at the height of 210cm. The detector is placed in sealed aluminium box. The driving speed during the exercise was chosen to be 30 km/h. Spectra were measured every 2 seconds and stored on the disk of the on-board computer. The survey consisted in driving along the road and observing the changes of the count rate in Co-60 and Cs-137 energy, as well as low-energy windows (to see if there was a presence of the scattered radiation and thus suggesting the proximity of other sources). The spectra were also observed, but mainly when the source had already been detected to check for the nuclide. The GR-660 spectrometer has no any buzzer to inform the crew that the car is close to the radioactive source (and it is not easy to be concentrated for many hours) – so we used hand-held GR-130 also on the car working in the survey mode as source presence indicator. When the source was detected from the car or when there was a suspicion of the radioactive source being nearby, we left the car and started the search on-foot using GR-130.

Data analysis

As soon as the source was found, the location was estimated by going around the area. The location of the source was determined using on-board DGPS giving the results both in RT90 and WGS84 formats. During the exercise we found the bug in the Exploranium software which corrupted the readout of the location data in RT90 format. For the first two days of the exercise we were not able to identify where the problem really is, but finally it was solved. It occurred that pushing the button, which saves the current screen configuration caused software to change GPS configuration file.

The identification of the nuclide was made using both GR-660 and GR-130 spectrometers. The source strength was determined by the GR-130 running dosemeter mode. The activity (Q) was estimated according to the formula:

$$H^*(10) = \frac{\Gamma_{amb} QB}{r^2 \exp(-\mu r)};$$

where $H^*(10)$ is ambient equivalent dose rate, Γ_{amb} – gamma constant for $H^*(10)$, B – build-up factor for scattered photons (assumed B=1), r – distance to the source, attenuation in the air $exp(-\mu r)$ assumed 1.

We assumed no shielding of the source because in fact it was not known. So the activities given by the PLK team are usually lower than those given by the REAC.

After the mission was completed we prepared NKS format files using NUCSPEC software.

Results

Our results are shown on the maps in below figures:

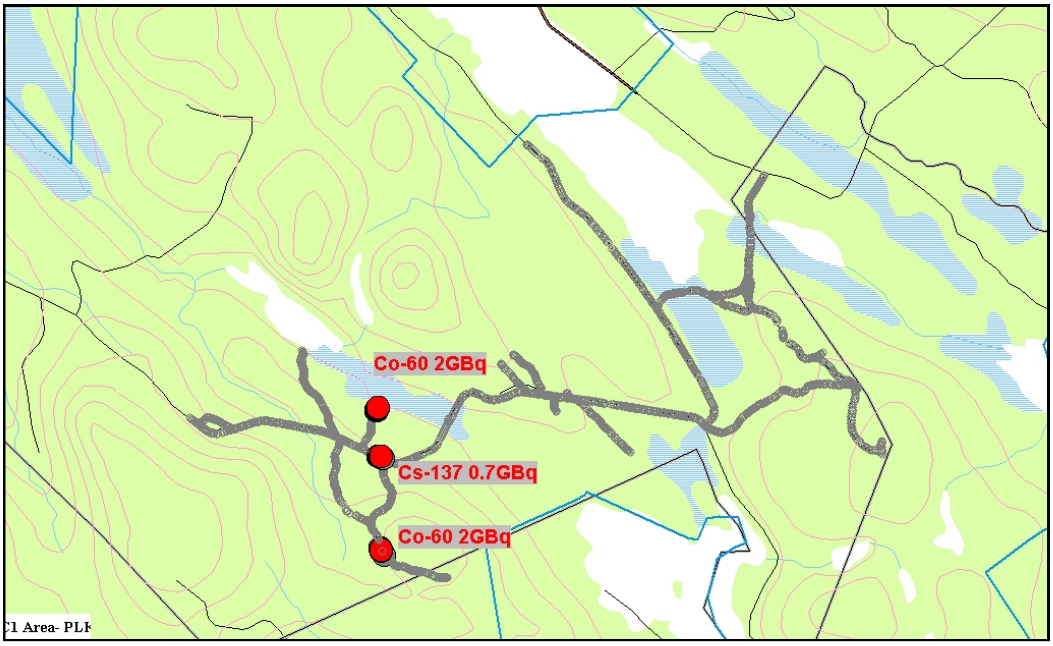

Figure 2. Area C1.

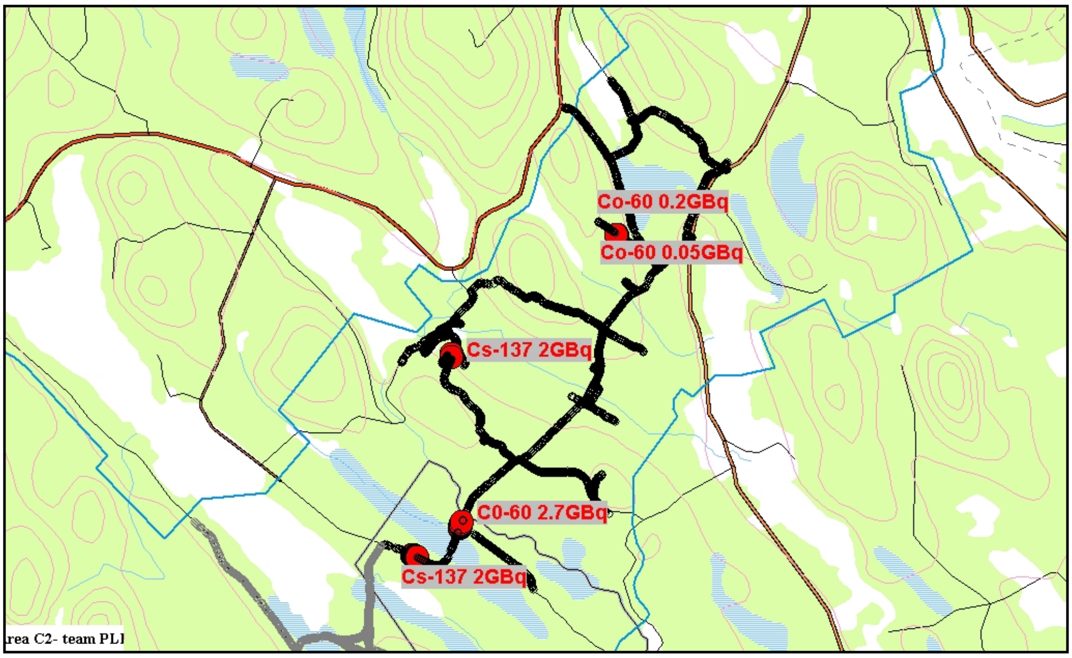

Figure 3. Area C2.

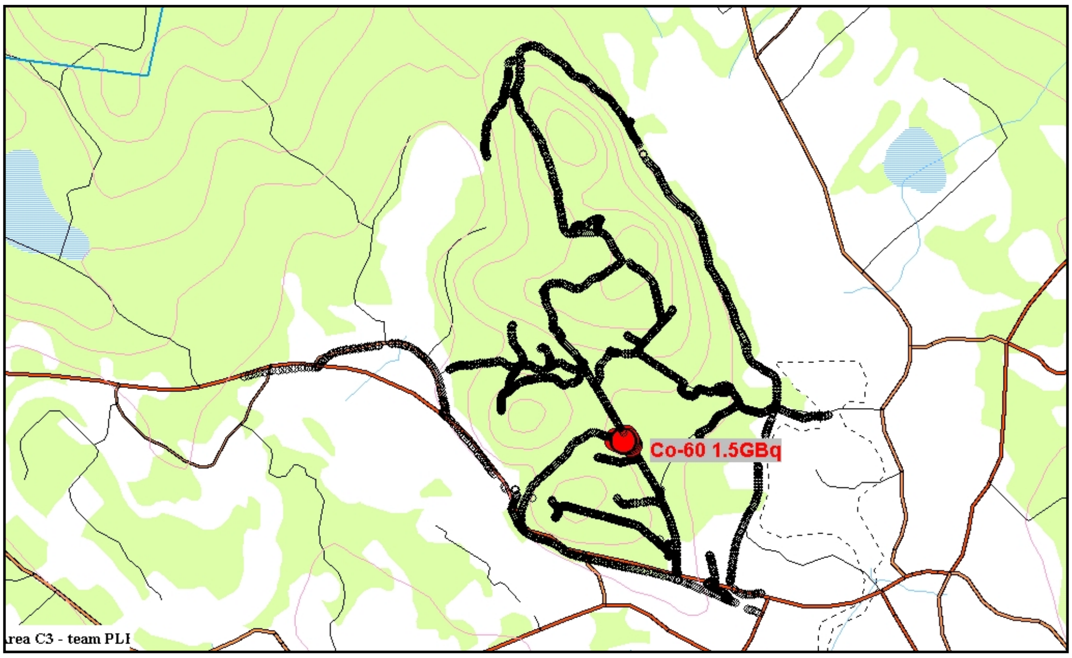

Figure 4. Area C3

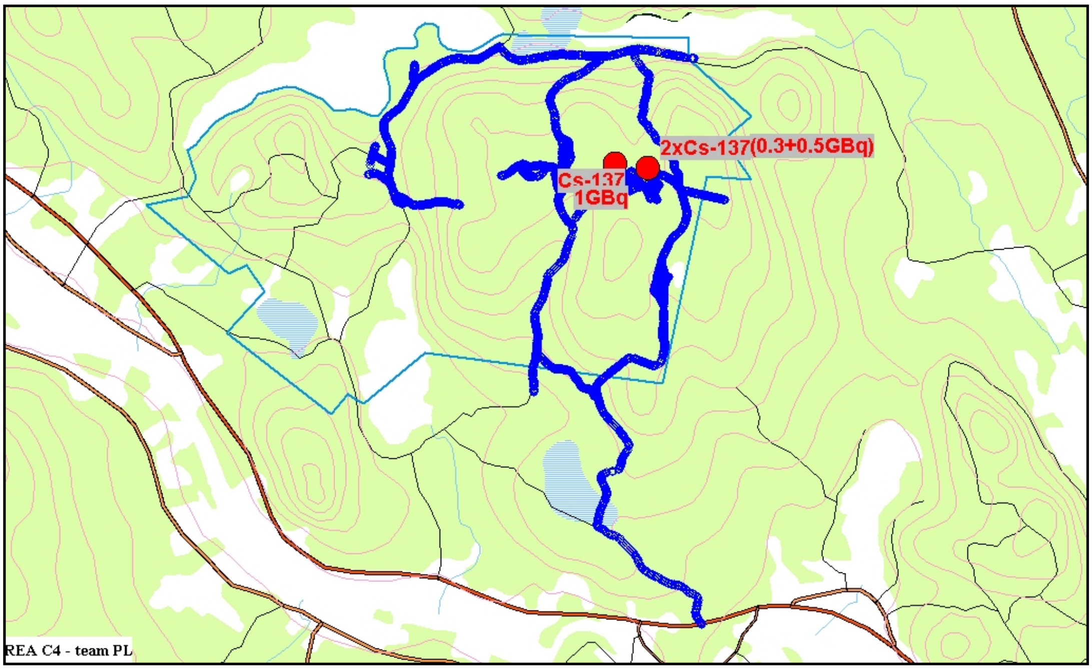

Figure 5. Area C4

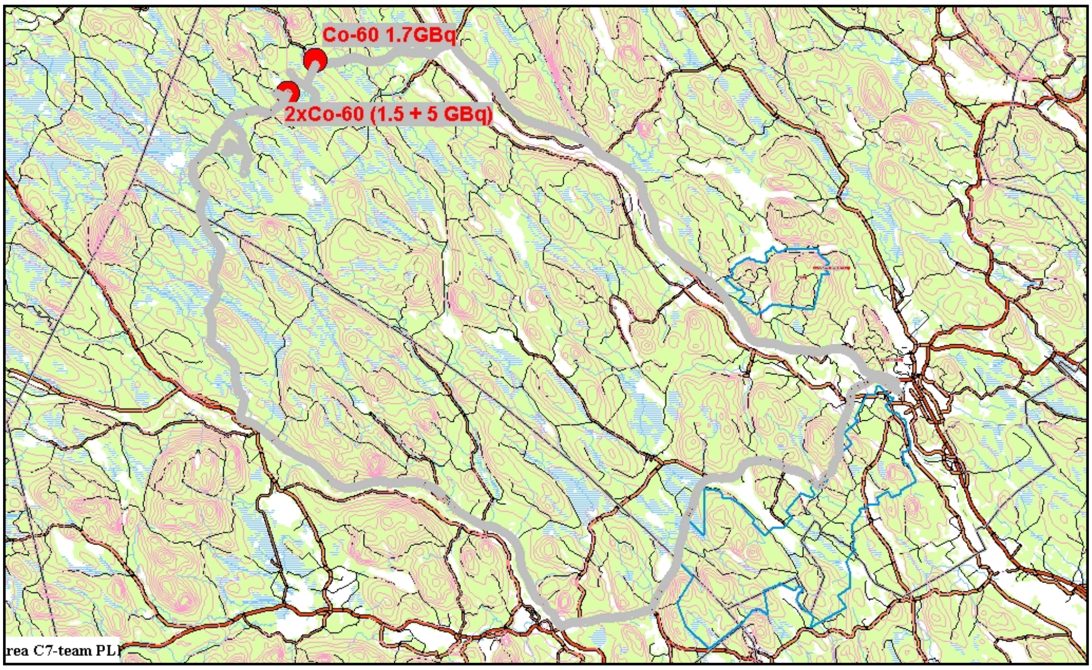

Figure 6. Area C7

It can be noticed that there is a difference of what was found and what was presented by the REAC. First and already mentioned is that due to the problems with RT90 coordinates in our system we had to provide REAC with the corrected SIRs. The corrected SIRs were both dictated by the phone and given on the paper when the mission was completed.

<u>Area C4</u> – we found the Cs-137 source with the REAC code 4:2, but obviously on REAC maps there are two Cs-137 sources and not exactly in the right place. We think there might be that REAC assistant did not mark the second report of the source finding as correction or we did not do it.

Our mistake was to take two Co-60 sources placed in the fire trench as Cs-137 sources – the measurement was done probably too close to the sources.

Area C3 – the Co-60 source found in this area (in fact the only source) was erroneously put by the REAC assistant into wrong C4 area with number 3:33. This might be caused by two factors: we entered C3 area some minutes before 12:00 which was the time for us to enter the area (but it was told on the radio) and problems with RT90 format reporting that day.

Conclusions

When the mobile spectrometric laboratory was to be put into operation it was already assumed that it would be used to search for lost and orphan sources. Before Barents Rescue 2001 some experiments had been made but not to a big extent. So it was in fact the first time for us to search for real sources in real conditions. During the Barents Rescue exercise we recognized that there are some improvements to be done, especially in the search procedure.

First - one has to be very concentrated while using GR-660 system, because it has no possibility to inform the operator that there is something strange or unusual around the vehicle. It has to be improved.

Second – there is a need to train on unusual sources (i.e. Am-241, Mo-99 etc.) to get used to the NaI spectra of different radionuclides. We are used to look at high-resolution HPGe spectra, and it is a need now to work with NaI spectra too.

Third – now we know more or less what is the “detection limit” for our mobile system.

Fourth – there is a need to have alternative GPS system in the car to assure that locations given by the team are correct.

Russia, teams RUK/RUL

Russian Team (RUK)

Nikolai Drozdov, Emercom

Team members

Car leader – 1

Engineer - spectrometrist - 1

Driver - dosimetrist - 1

Equipment

Gamma-survey set "Sensor"

DKS-96 radiometric dosimeter equipped with M,B units

DKG-02U radiometric dosimeter

PVP-4A aerosol sampler

PE-1110 water sampler

Portable notebook with PSH-600/128/10/FDD7CD/FM/NW/12'1TFT

Data transmitting system including R-23-02 radio modem, R-23-01 radio station and software package

Methods

Dosimetric

Detection of radionuclides using the spectrometric method.

Car speed – up to 40 km/h.

Data analysis

Source location detected using the GPS receiver; nuclide strength detected using the dosimetric equipment.

Results

19 ionising radiation sources were found.

Conclusions

We could not fully demonstrate our technical facilities

Bad radio communication with personnel at collection and analysis of data location

Problems using the reporting forms issued by REAC

Russian Team (RUL)

Nikolai Drozdov, Emercom

Team members

Car leader – 1

Engineer – dosimetrist – 1

Engineer – spectrometrist – 1

Driver – dosimetrist - 1

Equipment

45x50 mm CsI (TI) scintillation gamma-spectrometer

“Stalker” DKG-01-based gamma-survey system with a 63x63 mm NaI (Tl) crystal and GPS receiver

RM-1402M radiometric spectrometer

MKS-14ETS radiometric dosimeter

RM-1603 personal dosimeter

UVS-RM-1603 read-out device with software

PU-ZP/12 aerosol sampler

PE-1105 water sampler

Soil sampler with Edelman nozzle

Electronic balance “Tefal”

“Notebook” personal computer with software

Data transmitting system including R-23-02 radio modem, R-23-01 radio station and software package

Methods

Detection of radionuclides using the spectrometric method.

Dosimetric

Car speed – up to 40 km/h.

Data analysis

Source location detected using the GPS receiver, nuclide strength detected using the dosimetric equipment.

Results

10 ionising radiation sources were found.

Conclusions

We could not fully demonstrate our technical facilities.

The main task of the mobile radiometric laboratory is spectrometric analysis, but not air radiological searching.

Bad radio communication with personnel at collection and analysis of data location.

Problems using the reporting forms issued by REAC.

Russia, team RUM/RUN

Russian CGS Team (RUM/RUN)

Sergey Vasiliev,

Emergency Response Centre of Minatom. Russia

Introduction

Our mobile systems are intended for radiation monitoring of territories with the scale to some hundred kilometers.

Such monitoring **may** be conducted under a day-to-day condition for controlling a radiation situation at a territory that may potentially be subject to contamination, and **should** be conducted efficiently in an emergency to evaluate the actual contamination and obtain the data to take adequate countermeasures.

Main measured parameters

Main characteristics of a radiation situation, which are subject to be measured efficiently or evaluated with using mobile systems of radiation monitoring, include the following:

- **Dose rate of gamma radiation**
- **Isotope composition of main dose-forming nuclides**
- **Surface alpha- or beta-contamination**
- **Concentration of radioactive nuclides in the air.**

Exactly these characteristics determine a short-term forecasted dose and require an efficient evaluation. In accordance with the measured characteristics, selection of instruments is accomplished.

Besides that, when conducting the efficient monitoring for referencing the measured values to the locality, the data are required on **geographical coordinates** of a measurement point, i.e. it is necessary to use a navigation system with the sufficient space resolution.

Equipment

Thus, a set of instruments should be determined by a set of the main measured parameters.

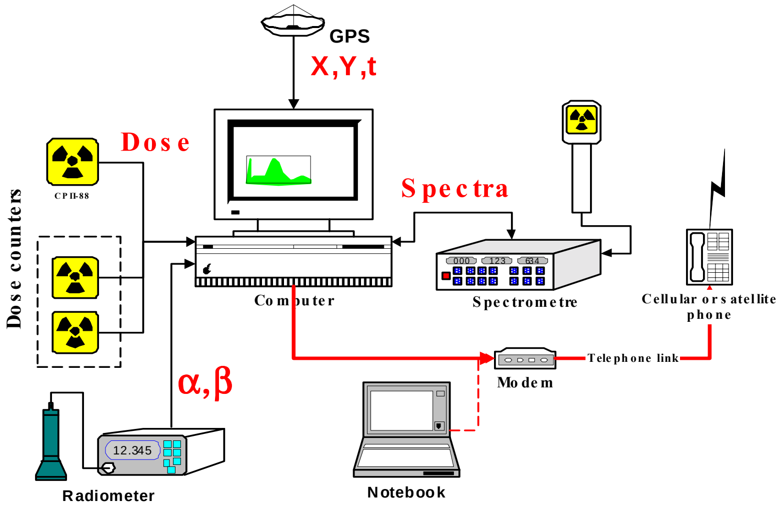

Fig.1 Equipment for Field Laboratory

Equipment

Additionally, one of our systems is equipped with a scanning device with the 150x100 mm NaJ detector for searching local gamma-sources.

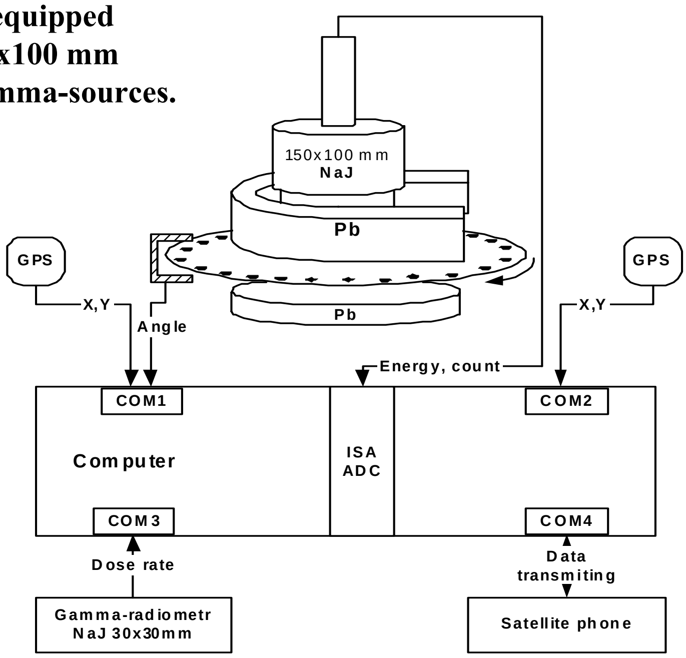

Fig.2 **Scaning system (RUN)**

Equipment

Computing devices and data communication devices

Computing devices of a mobile system should provide of collection, visualization, analysis, storage and transmission of the radiation monitoring data.
A system of communication and transferring data should provide an opportunity to transfer the monitoring data to the crisis center.
The real time data transfer mode seems the most desirable, and therefore, preference is given to wireless communication channels. The best characteristics, in this sense, relate to cellular and satellite digital communication channels.

Methods

Measurement of the dose rate along a journey route.
The dose rate is measured using the gamma-radiometer with 30x30 mm NaJ detector. Integration time is 1 second. The program records an average dose rate for a specified time interval or a specified distance traveled by a car. A measured value is entered to the database with referencing to coordinates of the car and time of registration. A mark of the measurement is put in the map, and a color of the mark depends upon the measured value of the dose rate (Figure 3). An operator might set a control level of the dose rate with the excess of which the program was beginning to generate a sound signal. The data accumulated were transmitted with using digital communication systems to the operation center.

Methods

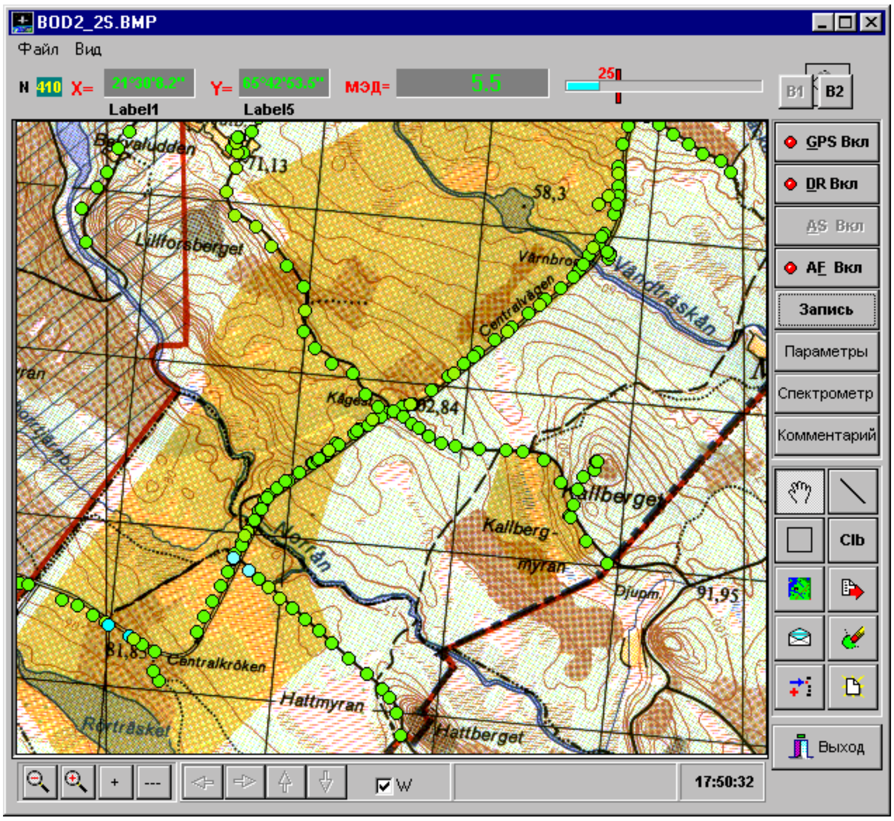

Fig.3

Methods

Measurement of a gamma-spectrometer count rate.
We used a portable gamma-spectrometer with a NaJ detector with the size of 63x63 mm. A special window was introduced to the program of the spectrometer, where the dependence of the count rate against time was represented in the selected energy range.
The operator was determining visually the presence of a peak in this window.

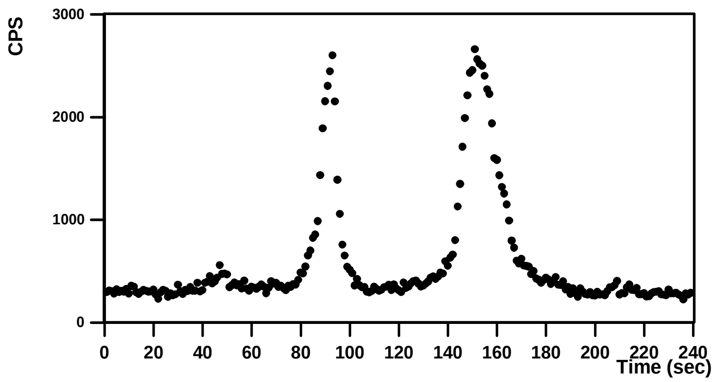

Fig.4

Methods

Usage of a scanning device.

A scanning device consisted of a NaJ detector and of a lead collimator rotating around it. The device driver recorded the count rate for five energy ranges in each of 32 sectors.

Mathematical processing gives opportunity to determine a direction towards a source (sources) on the absolute coordinates in the map.

Two or three measurements for various positions of the car were sufficient to obtain the coordinates of a source. This method has proved to be particularly useful when identifying several sources located close by and searching sources in locations difficult of access.

The system allowed to register reliably sources with the activity of about 1 GBk at the distance of 100 m.

Methods

The screen of a computer at the moment of determination of a direction on a sources

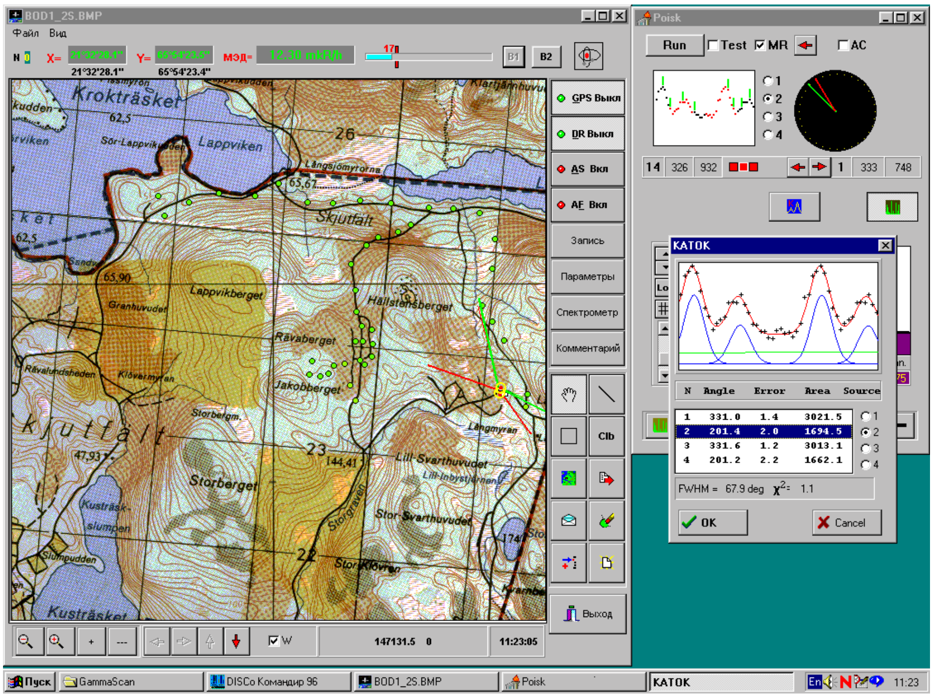

Fig.5

Methods

Determination of the nuclide composition and the activity of sources.
Measurement of characteristics of a source was performed with using a gamma-spectrometer with a NaJ detector with the size of 63x63 mm and the energy resolution of 9% for the energy of 660 keV. Processing was implemented with using a traditional method by full absorption peaks. Calculation of the activity was being conducted with using the curve of the detector efficiency measured for a point source at the distance of one meter. When calculating the activity, a distance to the source and absorption in the air were taken into account.
The main condition of measurement was selecting a direction where shield of a source was minimal. As a criterion of selection, we used the ratio of amplitudes of scattered and direct radiation, which ratio was being estimated visually by gamma-spectrum.

Results

Together (RUM & RUN) we found 16 sources, one of them was not identified.
When discussing the results, to my mind, the most interesting issue for consideration is to discuss sources of errors and difficulties arisen at the stages of searching, measuring and analyzing the results.
Searching sources.
Rather high activity of sources and their close location to the roads helped the most of teams to detect a considerable part of sources. To detect them, it was enough to drive carefully along all roads accessible for a car, and watch attentively for indications of devices. For detecting the most of sources, even the high sensitivity of devices was not required.
But...

Results

Weak sources or sources with low energy of radiation
Sources of molybdenum were an exception, since nobody detected them. However, as it seems to us, either they were located outside the area being accessible for driving by car, or energy of radiation was lower than the discrimination threshold of devices.

Sources located close by
Also we did not find one source located in a pipe under a road. Perhaps, too long time of integration (4 sec) and the presence of a “dead zone” (about 10 m) of a scanning device did not allow us to detect it.

Results

Double sources
Some difficulties arose in case of two sources located close by each other. In this case, radiation of the nearest source masked radiation of the further one, and made its detection difficult. In this situation, the presence of a scanning device helped us very much, in a scanning plot all sources of radiation were distinctly visible.

False sources
It is interesting to note the appearance of false sources bound up with scattering of radiation on surrounding objects. So, for example, we had to investigate carefully a group of trees at the distance of about 20 m from a source, because radiation scattered on them created a distinct peak on the screen of the scanning device. Unfortunately, this picture was not stored.

Results

Natural sources

Probably, all groups encountered a situation of rising the radiation background caused by the high concentration of natural radionuclides, and spent much time to investigate them. The natural origin of such anomalies may be identified by their space distribution and, of course, by the spectrum of gamma radiation.

Results

Determination of parameters of sources.
Coordinates of a source

The presence of GPS devices helped to determine correctly enough the coordinates of sources after their detection. Individual errors, in our opinion, occurred at the stage of registration and transmission of information. Such errors might be avoided by means of total automation of the process of determining the coordinates of a source and using a digital system of transferring the data.

Results

Determination of the isotope composition

The most difficulties arose when identifying the isotope composition of sources. The main reason was the presence of shield from several sides of a source. In this case, the main contribution to the dose rate from the shielded sides was made by low-energy scattered radiation, the spectrum of which did not allow to identify correctly a nuclide (Figure 6). Special difficulties arose when using software identifying automatically the isotope composition.
The only way out of this situation was determination of a direction where the shield was minimal, and full absorption peaks were appearing in the spectrum (Figure 7).

Results

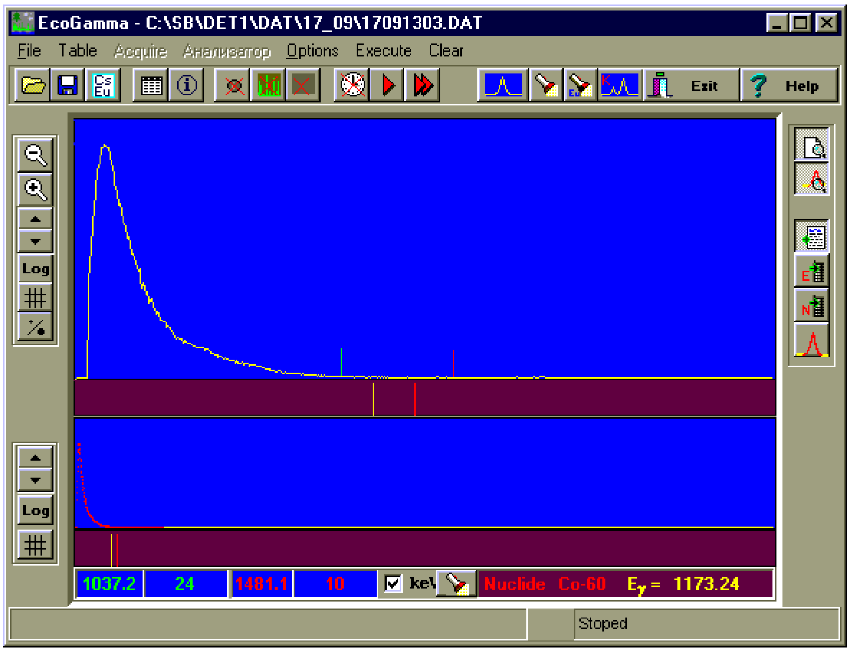

Fig.6 **Spectrum of scattered radiation (Co-60)**

Results

Fig.7 **In this Figure, the full absorption peaks are distinctly visible, as well as a backscattering peak indicating of the presence of shield at the opposite side.**

Results

Many groups had met difficulties when identifying Ir-192 and I-131. Probably, the data on these nuclides were absent in libraries used by the software, or algorithms of programs were not able to determine correctly the energy of the full absorption peaks. For such cases we recommend to all developers of software for analyzing gamma-spectra to add the image of main lines of the true spectrum of the selected nuclide to the image of spectra.

Results

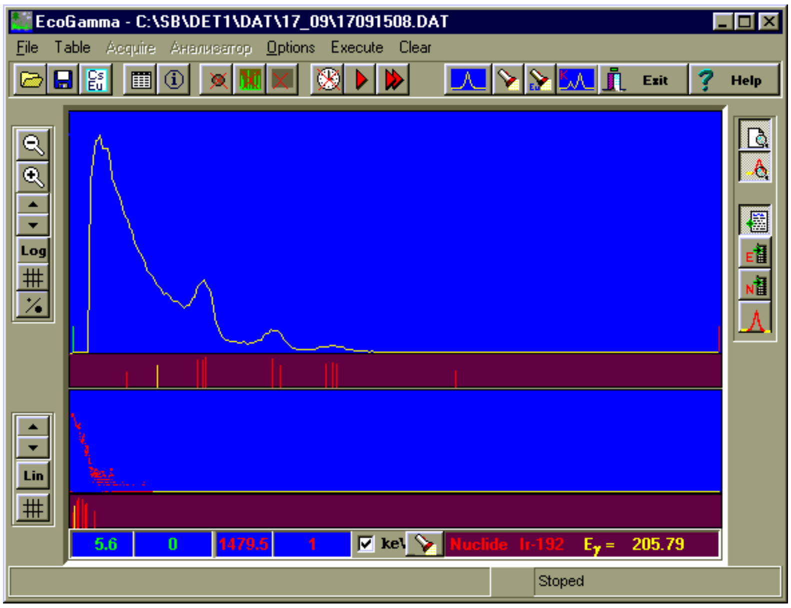

Fig.8 **Such picture is very clear, and facilitates considerably the task of identification.**

Results

Determination of the activity

When determining the activity of a source, the main error was produced by the presence of shield and the uncertainty in a distance to a source. The uncertainty of these parameters resulted the most considerable error.

Conclusion

The exercise have provided a unique opportunity to check abilities of all systems at all stages of work. We have understood which of our systems work well, which ones should be changed, and which ones should be created additionally.

The experience of contacts with colleagues and acquaintance with their systems were very useful. Unfortunately, the competitive nature of the studies prevented some groups from being interested more thoroughly in possibilities and results of other groups. I hope, here, we will be able to know each other better.

Conclusion

The presence of real sources in real conditions helped to watch such effects distorting a shape of a spectrum (absorption and scattering in the shield, in the air, in the surrounding objects, etc.), which were seldom observed when conducting measurements in laboratory conditions. Probably, it would be very interesting and helpful to demonstrate these effects with using one or two sources as an example and conducting more thorough investigation of them. Unfortunately, the lack of time did not allow to conduct such investigation.

Conclusion

The first experience of data exchanging was very useful. It is necessary to continue the development of unified formats of data exchange by common efforts, using the experience of each other.

A very important factor in a real emergency is the interaction of all participants. It is a very important problem, and, probably, the special exercise should be devoted to it.

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Conclusion

In conclusion, I would like to thank again the organizers of the exercise. We are always willing to cooperate, and will be glad if our experience may prove useful.

Sweden, team SEK/SEL

Swedish Team (SEK/SEL)

Team consisting of two cars in cooperation

Olof Karlberg ,SSI, main author (car 1).
Björn Sandström, FOI (car 1)
Lynn Hubbard, SSI (car 2)
Benno Bucher, Paul Scherrer Institute , Switzerland (car 2)

Equipment

Car 1

Ortec HPGE 36% with DigiDart MCA ,GPS and laptop computer (mobile monotoring system)

SRAT NaI Scintillator

SRV2000 GM-tube

RNI 10-S GM-tube

RNI 10-S with external GM-tube, GPS, Nokia 9000 Communicator cellular phone (automatic doserate monitoring system; data sent to remote database; no operator interactions)

Car 2

GDM (MCA and GPS) system with 3"X3" NaI Scintillator and laptop computer (mobile monitoring system)

Exploranium GR130 with BGO-scintillator

SRAT NaI Scintillator

Methods

The two cars worked in collaboration, thus being able to cover as much territory as possible. The HPGE and the Exploranium detectors were mainly used for source identification. The speed was varying but not more than 60 km/h.

Data analysis

The monitoring systems used the following data analysis methods:

- Spectrum plots (counts versus channel number)
- Time plots of variables like: counts in peak areas corresponding to possible nuclides, quotients high/low spectrum part, total counts etc.
- Rainbow spectrum plots
- Map plots
- Time series analysis with accumulated background subtraction (according to Hjerpe)

All variables with position were accumulated and saved in the NKS data format.

Results

There were 16 sources found. In most of the areas the best approach for finding sources was to drive and watch for suspicious military buildings or parked cars! It is therefore of no meaning to try to analyse why a certain source was found or not (a better procedure for testing the capability of the systems to find sources would have been to drive a common road where all sources were hidden).

It was not possible to use the HPGE system while the car was moving (at least on bad gravel roads) because of audio or vibration influences.

Conclusions

The SRAT scintillator was the most effective source finder, mainly due to its rapid response and audio output (in the long run, it is tiring to watch a computer screen continuously). Also the NaI monitoring system in car 2 was useful, although the volume of the detector was a bit small.

HPGE systems are not so useful for locating sources, due to the relatively low efficiency with only a few counts/channel. Since lost sources also could be shielded, which would decrease the non-scattered photon fluence, the advantage with the high resolution of the HPGE detector is lost.

The HPGE system could be used for source identification, however, especially if it is possible to remove the detector from the car and find the unscattered beam.

Sweden, team SEM

Swedish Team SEM

Thomas Hjerpe[§], Christopher Rääf[&], and Christer Samuelsson[§] (team leader)

Lund University, Sweden

§) Radiation Physics, The Jubileum Institute, Lund

&) Radiation Physics, Malmö

Equipment

Detectors and team inside a GMC van with an extended plastic roof and equipped with an interior 6 kW generator supplying 220 V AC. Handheld as well as car-bound GPS equipment for positioning. The software for treating and presenting spectral data was kindly supplied by SSI. The following detectors were used:

1. Carborne spectrometer HPGe (Ortec ruggidized) rel eff 100% + 8 k MCA (Dart, EG&G Ortec)
2. Carborne spectrometer NaI(Tl) 0.3 L (Gammadata GDM 40)
3. Handheld countmeter NaI(Tl) 0.1 L (Saphymo SPP_2_NF, "SRAT")
4. Handheld dosemeter, plastic scintillator (Bicron Microrem)
5. Handheld spectrometer NaI(Tl) 0.05 L (Bicron Fieldspec 130) This instrument was a demo instrument on loan Tue-Wend).

Methods

The objectives of our participation in Gamma Search Cell were to evaluate what a carborne team can do on its own, without any prior information concerning source locations or strengths. Thus, the recommended cooperation between an air team and a car team, the optimum use of resources in most real emergency situations, was not adopted.

Driving speed dependant on road condition but normally about 30 km/hour on gravel roads and 50 km/h on asphalt roads. Both spectrometers inside car at the rear end and shielded towards all side by the plastic roof of the car. The height above ground is approximately 2 m. for the two car borne spectrometers. The initial on-line strategy for finding sources was that one or several of the predefined alarm levels of the spectrometers should be exceeded and thus warrant the stop of the car. As it were, most sources seen from the car by us, were strong enough to be spotted already by the NaI count meter (Saphymo).

Once a source was found the car was stopped and in-car Ortec HPGe was used to identify the source by collecting an ordinary MCA spectrum over a few minutes. Some sources were heavily shielded or collimated and no peaks were seen in the Ortec HPGe spectrum if the detector was outside the primary gamma beam. In such a case the source was identified either by taking the Gammadata NaI spectrometer out of the car and into the primary beam or using the handheld Bicron Fieldspec (if available) in the primary beam. The activity of an identified gamma emitter was estimated by means of dose rate measurements on two different distances from the source, followed by calculation based on the inverse-square-law and the dose rate constant of the radionuclide in question.

Data analysis

The sampling time of the HPGe spectrometer system was 10 s, while the 512 channel NaI spectrometer integrated over 5 s. The spectral and positioning data from the HPGe detector were analysed by software developed by the staff of SSI and displayed on a PC computer display. For the HPGe spectrometer the net count rate in each energy window was calculated by subtracting the background estimated from count rates to the left and right of the full energy peak. The following energy windows were defined for the HPGe detector and the number of pulses was converted to the NKS file format:

1. Total cps (1-4095 ch)
2. Co-60 net cps
3. Co-57 net cps
4. Tc-99m net cps
5. Cs-137 net cps
6. I-131 net cps
7. Ra-226 net cps

For the GDM 40 NaI spectrometer 12 parameters based on 8 spectral windows were defined. Parameters1-5 are gross counts windows, 6-8 and 10-12 moving background gross counts parameters (MB), and parameter 9 is a Cs-137 window stripped from counts emanating from K-40 (PSC). In the MB 3/12 parameters the mean value of the latest 3 spectra is divided by the mean value of the preceding 12 spectra. For each MB 3/12 parameter an alarm level is defined, based on data from driving the car during natural background conditions (the alarm levels are in the parenthesis after each parameter below). The MB 3/12 algorithm is optimised for finding gamma sources emitting radiation isotropically and is less well suited for collimated sources affecting a single spectrum only.

1. CPS full spectrum gross cps (400)
2. I-131 window gross cps (80)
3. Cs-137 window gross cps (30)
4. Co-60 window gross cps (20)
5. K-40 window gross cps (15)
6. MB 3/12 High/Low ratio (1.3)
7. MB 3/12 Low/High ratio (1.3)
8. MB 3/12 Scattered (100-300 keV) (1.06)
9. PSC MB 3/12 Cs-137 window (2.0)
10. MB 3/12 I-131 window (1.7)
11. MB 3/12 Co-60 window (1.9)
12. MB 3/12 Cs-137 window (1.7)

Results

The 13 sources detected online are listed in Table 1. While comparing the performance of different equipments, it is worthwhile noting that our findings are based on:

1. Blind search (no air-team data consulted prior to search)
2. Small NaI spectrometer (0.3 L)

3. A moving background (MB) algorithm that was not optimized for collimated source geometries.

Table 1. Sources found and reported online by our team SEM. The first five columns display the source inventory as given by the Gamma Cell Search exercise management and the last four columns contain the figures we reported.

Nuclide	GBq	Code	RT E	RT N	SEM nucl	SEM GBq	SEM RT E	SEM RT N
I-131	9,25	1:2	1756005	7299224	I-131	9	1755999	7299226
Co-60	5	2:1	1764029	7307246	Co-60	3,4	1764035	7307241
Co-60	5	2:2	1764048	7307266	Co-60	3,1	1764055	7307263
Co-60	4x5	3:1	1766304	7316848	Co-60	0,9	1766302	7316882
Cs-137	0,4	4:1	1760923	7321390	Cs-137	0,18	1760915	7321376
Cs-137	2,5	4:2	1760488	7323895	Cs-137	0,18	1761205	7321747
Co-60	5	4:4	1761137	7323702	Co-60	1,7	1761137	7323696
Co-60	5	4:5	1761117	7323744	Co-60	1,4	1761116	7323746
Co-60	5	7:1	1725376	7340248	Co-60	1,3	1725392	7340242
Co-60	5	7:2	1721169	7340769	Co-60	0,75	1721159	7340769
Co-60	5	7:3	1718957	7338223	Co-60	6,6	1718955	7338224
Co-60	5	7:4	1718983	7338209	Co-60	5,8	1718991	7338206
Co-60	5	7:5	1711648	7331315	Co-60	0,3	1711645	7331282

Due to heavy collimation and errors estimating the source distance for in-house sources, several activity figures reported is too low. As it were, 12 out of 13 sources observed on-line by us, were strong enough to be revealed by the sound from small Saphymo NaI count meter.

The Cs-137 source under the nesting box (code 4:2) deserves a special comment. This source was the only source that was sensed by the large HPGe detector only. Neither the Saphymo NaI count meter nor the GDM 0.3 L NaI spectrometer gave any indication of a Cs-137 source from inside the car. Unfortunately, we reported erroneous coordinates for this source and consequently the REAC staff did not assigned any source code or SIR to our report. We have no explanation for the wrong coordinates. We can only guess that our handheld GPS received weak signals in the area and was not updated properly with the new position. Adding to the confusion is the fact that we in our notations has a dose rate of 6.5 microsievert per hour at 1.5 m from the lower end (which we by the way, thought was the position of the source) of the metallic rod hanging down from the nesting box. Even if we correct for our misunderstanding of the source position, the noted dose rate is a factor of 10 too low. Misreading 65 microsievert per hour as 6.5 is a possible explanation for our erroneous activity estimate of source 4:2.All our equipment kept operational throughout the exercise and no problems with energy drift, microphony etc occurred. The only exception was a PC laptop that has to be exchanged due to a destroyed serial port caused by our own erroneous handling. On the negative account is also that the GPS positioning from our car borne systems was occasionally lost. The software from SSI for both the HPGe MCA Dart and the NaI(Tl) gammadata equipment was invaluable for sorting, displaying and alerting us on incoming spectral data. However, some parts of the software, e.g. waterfall display, need further development to be useful during real time conditions.

Conclusions

It is noticeable that the expensive HPGe detector was necessary for only 1 (source 4:2) out of 13 sources. This is however, more an effect of the special source geometries and strengths during the exercise, than a deficiency in the HPGe spectrometry system itself.Clearly, the post-processing of the spectral data from the Gamma Search Cell will be an important tool for improving real-time evaluation and presentation techniques. Especially for the HPGe spectrometer one can expect improvements in real-time source detectability as the on-line presentation software from SSI used by us is just in its infancy.

Acronyms

MCA = Multi-Channel Analyser

MB = Moving Background

PSC = Potassium Stripped Counts

REAC = Radiological Emergency Assessment Centre

SIR = Source Identification Report

SSI = Swedish Radiation Protection Authority

Sweden, team SEN/SEP

Sweden, Team SEN & SEP

Christina Greis[1], Håkan Grundin[2], Mats Isaksson[2], Håkan Pettersson[1] and Raine Vesanen[2].

[1]Department of Radiation Physics, Health Faculty, Linköping University, SE-581 85 Linköping, Sweden. [2]Department of Radiation Physics, Göteborg University, SE-413 45 Göteborg, Sweden.

Equipment, Methods and Data analysis

A NaI(Tl)-spectrometer, GR-130 MiniSpec (Exploranium, Canada) with a 74 cm^3 crystal, was used as a survey instrument in order to locate the sources. The same instrument (in dose rate mode) was also used for determination of the ambient dose equivalent rate at an estimated distance from the radiation source. The sources where identified with a 10% rel.eff. HPGe-detector (EG&G Ortec inc., USA) except for two remote sites where the MiniSpec was used, due to its portability. The germanium spectrometer was connected to an Inspector™ multi channel analyzer and a Genie software (both Canberra inc., USA) run from a laptop PC. The source coordinates were identified with a Garmin GPS 12 (Garmin International inc., USA)

Spare instruments were also calibrated and tested during the first days, but not used during the LIVEX missions. These comprised: a Garmin GPS 50, a 103 cm^3 NaI(Tl) detector connected to a Nomad 92X-P multi channel analyzer with Maestro software (both EG&G Ortec inc., USA) run from a laptop PC, and four RNI 10/SR (RNI AB, Sweden) dose rate instruments, which we also carried during the missions for personal safety.

The driving speed was 30-50 km/h. The NaI(Tl)- and the HPGe- detectors were situated at window height inside the car. Indications were based on (i) alarm levels, i.e. when dose rates exceeded ambient background dose rate levels, the acoustic alarm indicated presence of a source, and (ii) simultaneous monitoring of suspicious peaks in the germanium spectrum. On indication of higher activity, the suspicious part of the road was searched at lower speed. However, most of the time additional search had to me made on foot around the areas with the survey instrument. When a source was found, the radionuclide was identified by manual inspection of the gamma spectrum. Then the distance to the source was estimated by using the inverse square law. A reading of the ambient dose equivalent rate was then taken at a given distance. The shielding material and its thickness was estimated. The data was finally analyzed while travelling towards the next source; (i) The source apparent activity was determined by using the dose rate, distance and the gamma constant for the identified radionuclide. (ii) The estimated true activity was calculated taking the shielding material and its thickness in consideration by using attenuation coefficients for the actual gamma energies. The data was reported whenever possible to the REAC by cellular phone.

Results and discussion

In total there were 29 different sources in the gamma search cells. Some of the sources were difficult to find and identify. On average 10 of the 29 sources were correctly identified by the car-borne teams. None of the teams succeeded in identifying more than 15 sources correctly. We were able to locate 13 (45%) of the sources. However, identification was made on all of the located sources, and thereby we could calculate the apparent activities. In four cases we could identify the source shielding material and estimate its thickness, to such extent that it was possible to make an estimation of the true activity (table 1). The differences between actual activities and estimated true activities are probably due to uncertainties in the apparent activity estimates and in the estimated thickness of the shielding materials. In addition, the attenuation factors for inhomogeneous materials such as concrete can differ quite a lot due to different types of bulk material, see sources 2:1 and 4:4 in table 1.

Table 1. Data for all of the sources in the gamma search cells. The results for the SEN&SEP teams are presented under the apparent activities and the estimated true activities and the deviation between estimated true activities and the actual activities are also shown. The table also shows the number of car borne teams that located the source and how many of them identified the found source correctly.

Existing Sources	Actual activity (Gbq)	Apparent activity (GBq)	Estimated Activity (GBq)	Deviation (%)	Number of teams that	
					Located	Identified
1:1 Co-60	5	4,3	4,5	10	3	2
1:2 I-131	9,25	9,5	10	8	14	6
1:3 Co-60	5				10	8
1:4 Co-60	5				15	10
2:1 Co-60	5	3,7	3,7	26	15	12
2:2 Co-60	5	0,15			15	9
2:3 Mo-99	3,1				0	0
2:4 Mo-99	18				0	0
2:5-1 Cs-137	1,5				0	0
2:5-2 Co-60	0,06				0	0
2:6 Am-241	0,0004				1	0
3:1 Co-60	20	1,04			16	15
4:1 Cs-137	0,4	0,45			8	6
4:2 Cs-137	2,5				10	9
4:3 Ir-192	13				5	4
4:4 Co-60	5	1,7	8,6	72	13	7
4:5 Co-60	5				10	2
4:6 Cs-137	1,3	0,32			6	2
4:7 Cs-137	1,9				1	1
7:1 Co-60	5	1,1			10	9
7:2 Co-60	5	2,9			11	10
7:3 Co-60	5	1,06			13	12
7:4 Co-60	5	6,4			7	6
7:5 Co-60	5	0,071			9	8
7:6 Ra-226	Nat				0	0
7:7 Ra-226	Nat				1	0
7:8 Ra-226	Nat				0	0

Conclusions

We learned a lot from this exercise and our results are quite encouraging. However, some improvements in source findings seem to be necessary. Some reported data were incorrectly given at the Barents rescue web page, maybe due to communication or reporting error, which should be avoided in the future. Survey instruments like the GR-130 MiniSpec seems to be quite versatile for this kind of investigations. However, car borne detectors need larger crystals (>74 cm^3) if sources of lower activity are to be located or if driving at higher speed is desirable. Further, for the purpose of dose-rate and or spectrometric tracking, the instruments should include facilities for simultaneous GPS-recording. Cars with off-road capabilities are also recommended for such missions.

Session 4

Workshop: Monitoring for radioactivity

Seminar workshop

Thomas Ulvsand, FOI

The participants were divided into six groups. The groups were given the task to discuss certain questions provided by the seminar management, on nuclear emergency preparedness, mobile monitoring, and nuclear exercises.

Group members and questions are given below. The chairman of each group is given in bold letters. Identical questions were given to groups 1 and 2, and similarly for groups 3 and 4, and to groups 5 and 6, respectively. After the two groups follow the questions they were asked to discuss in bold letters and a summary of their answers.

Group 1

Wolfgang Fehringer	Federal Ministry of the Interior
Christer Samuelsson	Lund University
Visvaldis Graveris	Latvian Environment Agency
Mark Dowdall	Norwegian Radiation Protection Authority
Mats Wedmark	Geological Survey of Sweden
Simon Karlsson	Swedish Radiation Protection Institute

Group 2

Andreas Polaschek	Gendarmerie Headquarter of Lower Austria
Peder Beausang	FOI, Swedish Defence Research Institute
Andrejs Dreimanis	Radiation Safety Centre
Peter Hagthorpe	Geological Survey of Sweden
Robert Finck	Swedish Radiation Protection Institute

What kind of information concerning radioactivity in the environment is needed in an emergency situation?

It is important to know the nuclide(s),physical nature, activity concentration, extensiveness, dose rate and the radiation field. It is not likely that measurements will give the first information.

Can AGS/CGS information be integrated into present decision support systems?

It is important, but there is an uncertainty about the way to do it. There can be problems with information exchange due to different systems. Data presentation is crucial

What is the proper way of reporting measurements of fallout activity?

Reports must go in classical ways about: source identity, area affected, homogeneity and equivalent surface activity, for which it is important to have an agreement on the definition.

What is the proper way of reporting measurements of lost sources?

The following should be reported: nuclide(s), activity and uncertainty, physical nature, beam characteristics, dose rate as a function of distance, position coordinates and safe distances.

Group 3

Frank Andersen	Danish Emergency Management Agency
Jarkko Ylipieti	STUK-Radiation and Nuclear Safety Authority
Mark Smethurst	Geological Survey of Norway
Boris Petrov	Emergency Response Centre of Minatom, St.-Petersburg
Sergey Vasiliev	Emergency Response Centre of Minatom, St.-Petersburg
Sören Byström	Geological Survey of Sweden

Group 4

Kim Bargholz	Danish Emergency Management Agency
Mikael Moring	STUK-Radiation and Nuclear Safety Authority
John Mogaard	Geological Survey of Norway
Kenneth Lidström	FOI, Swedish Defence Research Agency
Ari Tryggvason	Geological Survey of Sweden
Thomas Ulvsand	FOI, Swedish Defence Research Agency

Is the information from AGS/CGS systems useful for a nuclear emergency organization?

Yes, and not only useful, it is necessary.

Can the role of AGS/CGS after the next major accident be foreseen?

It will be dependant on the accident scenario, but mapping and nuclide identification will be important.

What are the typical tasks we can expect for AGS/CGS?

To measure and to collect and process data for estimation of doses at populated areas. There are differences between countries about how early in the accident scenario AGS and/or CGS will be used, for example during or after plume passage.

If the role of AGS/CGS is to quantify fresh fallout - are we able to?

Yes we are, but there are restrictions. For AGS bad weather or lack of relevant calibrations can give difficulties. There also will be problems to identify nuclides if NaI-detectors are used in fresh fall-out. For CGS there is the risk of getting the vehicle contaminated.

If the role of AGS/CGS is to find and identify lost sources - are we able to?

Yes we are, but the search will not be effective in all situations. The success will be dependant of shielding, source activity, gamma energy, distance and LUCK. AGS scan an area and CGS is used for local follow up. Mobile sources will be hard to find.

Group 5

Anders Damkjær	Risø National Laboratory
Markku Kettunen	The Finnish Defence Forces Research Centre
Arunas Gudelis	Institute of Physics
Kerstin Lundmark	Swedish Radiation Protection Institute
Olof Karlberg	Swedish Radiation Protection Institute

Group 6

Helle Karina Aage	Technical University of Denmark
Christian Bourgeois	CEA/France
Thor Engøy	Norwegian Defence Research Establishment
Nikolai Drozdov	EMERCOM of Russia
Victor Vinnikov	EMERCOM of Russia
Hans Mellander	Swedish Radiation Protection Institute

Should the CGS and AGS teams be focused on operational aspects or should they be scientific groups focused on research?

They must be focused on both, to have a parallel development of operational and scientific aspects. It is important with collaborations inside and between nations.

What scientific questions should be solved, in order to improve mobile measurements?

Better software for online- and post processing, with minimum operator interface. Standardization of communication equipment. Harmonize reporting units, for example equivalent surface activity.

How do we run a continuous operation for several weeks?

A lot of personnel will be needed, both for measuring operations and for analysis support. Cooperation between several groups will be important, like sharing team members. Equipment with alarm triggers, like sound, will improve the effectiveness.

How do we prepare for the unexpected?

By using a scientific approach and to look for new (and far fetched) scenarios and evaluate them. It is important to have back-up systems and to exercise.

Assuming a scenario like the one at Barents Rescue LIVEX. What will the monitoring teams require of the emergency management?

They will need accommodations, food and beverage, logistics. There must be a command/coordination centre (like the REAC). They will need communication, technical and scientific support. Effective reception of data, like coordination between AGS and CGS will be important.

Session 5

Future work

ECCOMAGS

Hans Mellander, SSI

ECCOMAGS PARTNERS

- Scotland
- Germany
- Sweden
- Denmark
- France
- Austria
- Portugal
- Switzerland

- University of Glasgow
- Bundesamt fuer Strahlenschutz
- Swedish Radiation Protection Authority
- Technical University of Denmark
- Danish Emergency Management Agency
- Commissariat à l'Energie Atomique
- Geologische Bundesanstalt
- Instituto Geologico e Mineiro
- Swiss Federal Institute of Technology Zurich

ECCOMAGS OBJECTIVES

- The project objectives are to conduct an international calibration exercise for airborne gamma spectrometry, with the aim of validated standard procedures for measurement of deposited environmental radioactivity and dose rate, and to coordinate further European research leading to improved capabilities for emergency response.

ECCOMAGS BUDGET

- Total budget 650000 EUROS
- Partners exercise participation 18000 EUROS

ECCOMAGS TIMETABLE

- Draft protocols to be finalised autumn 2001
- Precharacterization field work November 2001
- Precharacterization report March 2002
- Exercise May/June 2002 (weeks 22 & 23)

ECCOMAGS exercise tasks

- To accurately measure three calibration areas that has been precharacterized
- Demonstrate a cooperation capability by producing a common mosaic map
- Extras?
- Ground teams are supposed to contribute to the area characterization

ECCOMAGS CONTACT INFO

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- Fax: +44 (0)1355 229898
- Email: J.McLeod@surrc.gla.ac.uk

Appendix 1

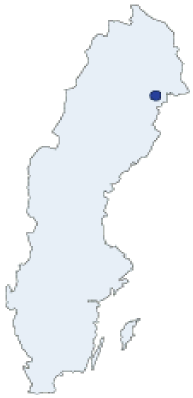
Air Search Areas

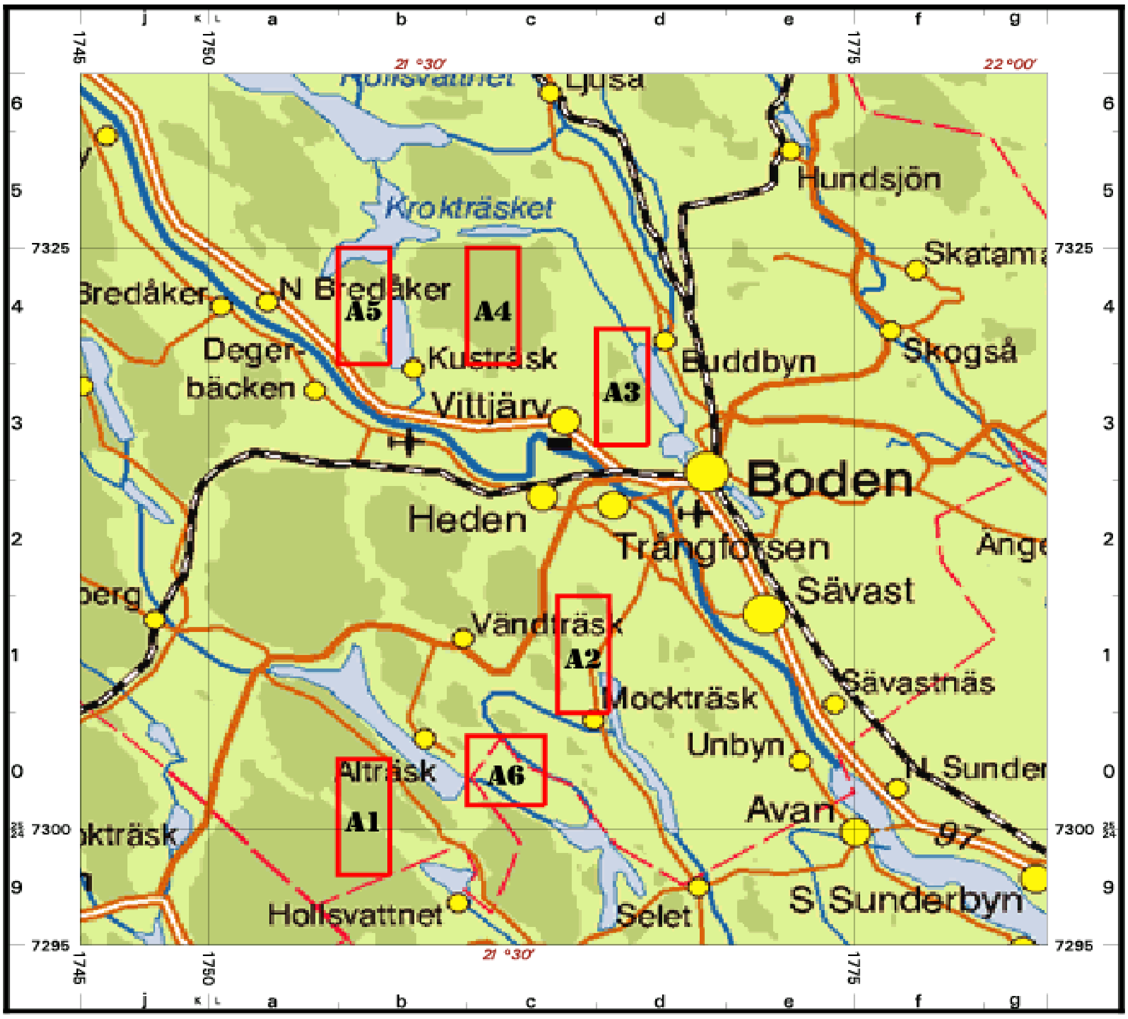
Car Search Areas

Air Search Areas

Underlagskarta
GSD/SNA
Air Search
Overview Map (GSD/SNA)

Statens strålskyddsinstitut
Swedish Radiation Protection Authority
2001





Statens strålskyddsinstitut
Swedish Radiation Protection Authority

Topografiskt underlag enligt avtal med Lantmäteriverket.
Geofysiskt underlag enligt avtal med Sveriges geologiska undersökning.
Geografiska längden är räknad från Greenwich. Gauss' projektion.

0 2.5 5 7.5 10 12.5 km

Barents Rescue 2001

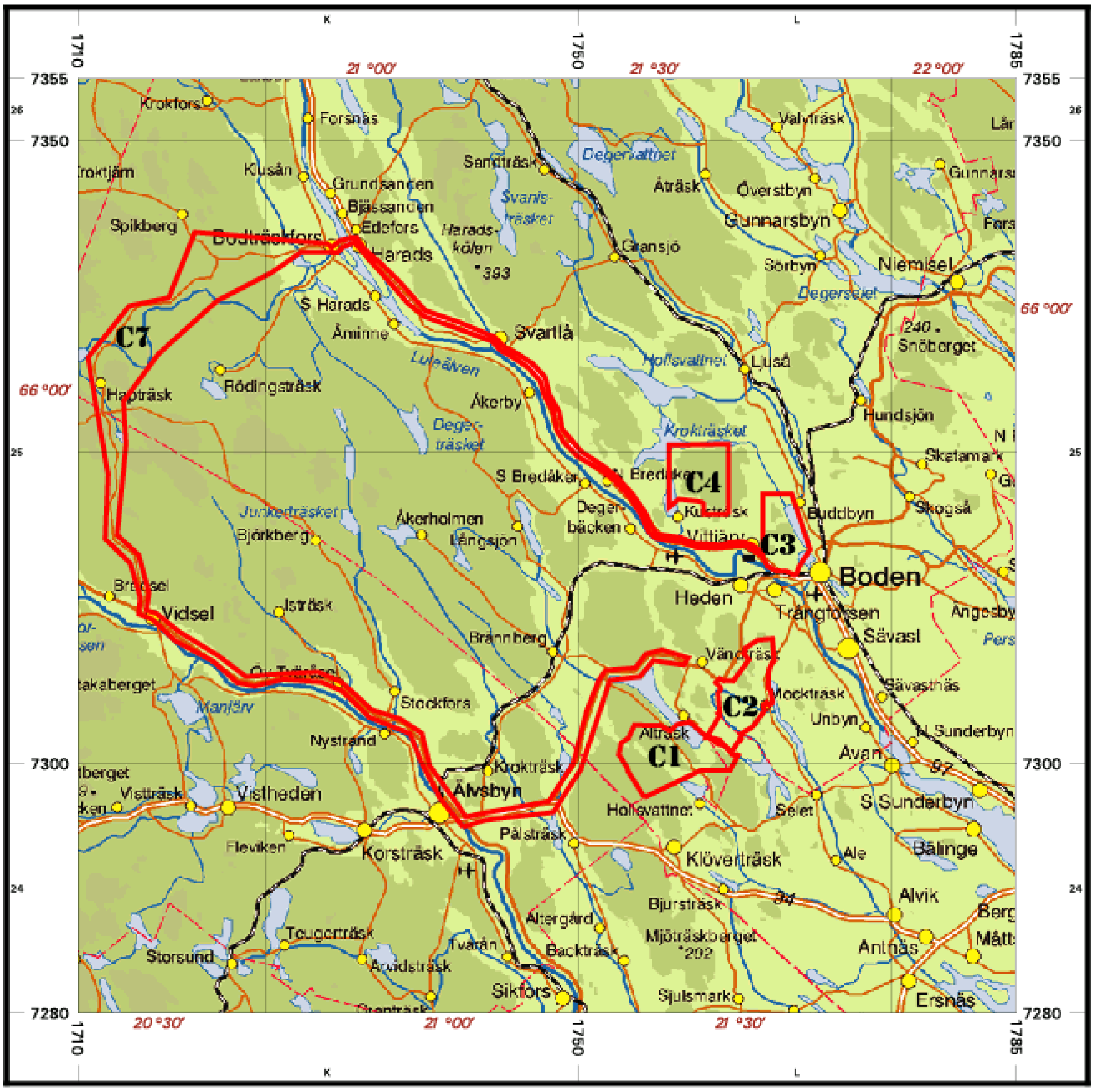
Skala 1 : 250 000

Car Search Areas

Underlagskarta
GSD/SNA
Ground Search
Overview Map (GSD/SNA)

Statens strålskyddsinstitut
Swedish Radiation Protection Authority

2001



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Topografiskt underlag enligt avtal med Lantmäteriverket.
Geofysiskt underlag enligt avtal med Sveriges geologiska undersökning.
Geografiska längden är räknad från Greenwich. Gauss' projektion.

0 5 10 15 20 25 km

Barents Rescue 2001

Skala 1 : 500 000

Appendix 2

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Title	NKS/SRV Seminar on Barents Rescue 2001 LIVEX. Gamma Search Cell
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No. of pages	281
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Abstract	Proceedings of the NKS/Barents Rescue 2001 LIVEX seminar, held at Rosersberg Castle, Stockholm, on October 23-24, 2001. At the seminar, results from the Gamma Search Cell of the Barents Rescue 2001 LIVEX were presented and the performance and experiences of airborne and car-borne teams that took part in the exercise were evaluated. In the Gamma Search Cell, the mobile teams found about 50 % of a large number of radioactive sources hidden within the exercise area. The exercise demonstrated that it is necessary to practise and test equipment under out-door conditions. By which method a source is found is important information in the evaluation of the result. Complementary methods are necessary to find hidden sources. For heavily shielded sources methods based on scattered radiation should be developed.
Key words	Emergency Preparedness; Gamma Spectroscopy; Radiation Monitoring; Radioactive Sources; Nuclear Exercises.

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